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AUTHORITY

AFAL ltr, 17 Aug 1979

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WADC TECHNICAL REPORT 53-106

TENSILE AND TENSILE-FATIGUE PROPERTIES OF TRANSPARENT ENCLOSURE ATTACHMENTS FOR AIRCRAFT

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ELBER LATHAM
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SWEDLOW PLASTICS COMPANY

APRIL 1953

Statement A
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McGregor & Werner, Inc., Wakefield, Mass.
Oct. 30, 1953 100

FOREWORD

This report was prepared by Swedlow Plastics Company under Air Force Contract Number AF 33 (038)-22456. The work was administered under the Special Projects Branch, Aircraft Laboratory, Wright Air Development Center, with Captain F. M. Cooper acting as project engineer. The project was identified by RDO No. 453-303 "Development of Stronger and More Fatigue Resistant Attachments for Transparent Materials".

ABSTRACT

Fifteen types of edge attachments, eight for monolithic acrylic material and seven for laminated acrylic material were designed, fabricated and tested for tensile strength at room temperature and -65°F, and in tensile-fatigue at room temperature. Thirteen of these types were designed using MIL-P-6886 acrylic material and two were designed using MIL-P-5425 acrylic material.

Though ultimate tensile strengths vary widely depending on design and materials used in the attaching edge, it appears that the tensile-fatigue limit in all cases where good engineering design practices are maintained approaches one pound per mil thickness per inch of width of MIL-P-6886 transparent acrylic material at 500,000 cycles. Although MIL-P-5425 acrylic material appears to have a slightly greater endurance limit, insufficient data are available to definitely draw such a conclusion.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

James O. Cobb Col, USAF
for DANIEL D. McKEE
Colonel, USAF
Chief, Aircraft Laboratory
Directorate of Laboratories

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ENCLOSURE ATTACHMENTS FOR AIRCRAFT

Late in World War II it became apparent that transparent enclosures for aircraft could no longer be attached by the simple means previously used in unpressurized craft. This realization induced a general reaction toward edge reinforcement in the technical sections of all concerns involved. Solutions to the problem were in many cases independently evolved and consequently many types of attaching edges appeared.

The basic purposes for this attaching edge were threefold:

1. To increase bearing strength.
2. To prevent the inception of fracture in the body of the transparent material.
3. To prevent propogation of fracture from the attaching edge into the body of the transparent material.

The direction of attack to achieve these purposes has been universally similar in that some attaching edge has been cemented to the transparent enclosure. The materials used for this purpose have varied widely and include cast acrylic reinforcing strips, rubber extrusions, stainless wire screen - acrylic laminates, square woven Fiberglas cloth-acrylic laminates, and free Nylon loops. More recent inovations have included new weaves of glass cloth as satin weaves and unidirectional weaves built into acrylic laminates and many synthetic fiber acrylic laminates, most notably Orlon and Dacron.

This report covers engineering data sponsored and financed by Wright-Development Center, Wright-Patterson Air Force Base, Dayton, Ohio, on tensile strength and tensile-fatigue of fifteen edge attachment designs (see Appendix II, Page 14 through 29). These designs are similar to six which have been in actual use in the past several years. However, they have been arbitrarily adapted to both monolithic and laminated acrylic sheets as well as to standard caliper transparent stock to reduce the number of variables. Monolithic designs are all adapted to transparent material .312 inch thick, and laminated designs are all adapted to .500 inch laminated material consisting of two outside skins of acrylic sheet .150 inches thick, with a center ply of polyvinal butyral .200 inches thick. All designs were developed using MIL-P-6886 transparent material except STS-022 and STS-023 (Appendix II, Page 28 and 29) in which MIL-P-5425 transparent material was used. Otherwise these two designs were duplicates of STS-001A and STS-002 respectively.

Forty two specimens of each of the fifteen designs were fabricated for test purposes in thirteen inch long panels and the specimens were cut and finished from the panels. Materials used in the fabrication of these specimens are described in Appendix I, Page 12 and 13.

All tensile and tensile-fatigue tests were conducted on rigid attaching edge specimens in bearing on two evenly spaced 1/4 inch pins (see Figure 1, Page 5). The Nylon loop types were tested with a lateral locking pin in a slot simulating actual frame installation.

Ultimate tensile strengths were determined for each of these designs at both 70°F. ± 5°F. and -65°F. +0°F. - 5°F.

Table 1 shows these values as averages of 10 specimens in each case. The wide variation in these average values is due to the original design strength and the comparison of the specimen design with the corresponding ultimate tnesile makes apparent the reasons for corresponding high and low values. The erratic increase or decrease due to thermal depression may be of design interest but will not be discussed in this report. Tensile test details and data are in Appendix III, Page 30 through 35.

TABLE 1

AVERAGE TENSILE STRENGTHS

DESIGN	TENSILE STRENGTH IN LBS. PER INCH OF WIDTH AT		INCREASE (+) OR DECREASE (-) AT -65°F.	
	+70°F ± 5°F.	-65°F.+0°F -5°F.	Lbs/inch	Percentage
STS-001A	1379	1728	+ 348	+ 39.9
STS-002	1771	2201	+ 430	+ 24.3
STS-003A	913	1019	+ 106	+ 11.6
STS-004A	1391	1362	- 29	- 2.1
STS-005	598	773	+ 175	+ 29.3
STS-007	331	800	+ 469	+141.6
STS-008	630	605	- 25	- 4.0
STS-009	628	769	+ 151	+ 22.5
STS-010	1076	1148	+ 72	+ 6.7
STS-012	1222	1533	+ 311	+ 25.5
STS-013	1803	1416	- 387	- 21.5
STS-014A	1491	1605	+ 114	+ 7.6
STS-015	1467	2041	+ 574	+ 39.1
STS-022	1522	2052	+ 550	+ 36.4
STS-023	1206	2771	+1565	+129.7

Equipment for tensile-fatigue testing was specially designed and constructed to meet the requirements of this program. The design requirements were as follows:

1. Load accuracy to ± 1%.
2. Elongation from 0 to 10% in a 10 inch specimen.
3. All loads in the positive or tensile direction with a minimum load in each cycle of zero pounds.
4. Adjustable maximum load in each cycle from 100 lbs. to 5,000 lbs.
5. Cycling rate of approximately 15 cycles per minute.
6. An even division within the cycle between (a) at rest, or zero load, (b) apply stress, (c) maintain stress, (d) decrease stress.

The design finally evolved to meet these requirements was a simple beam mechanism with a variable fulcrum. Load accuracy was maintained through careful design, accurate calibration and careful operational techniques. Elongation variations were made possible by the use of a variable cam drive. Stress was applied by dead weight application at the aft end of the simple beam through a

cam operated rocker arm. As the dead weight came to rest on a platform, no compressive load was applied to the specimen. Cycling rate was arrived at by a simple mechanical speed reduction to the drive cam. Item 5 above posed a difficult problem in that normal fatigue cycles follow a sine wave pattern. The equipment design for this program arrived at four even quadrants of cycle in the following manner. The "at rest" position was maintained at no load by resting the dead weight load on a tray. In the second quadrant stress was applied by lifting the dead weight on a restrained helical spring calibrated to support slightly more than the dead weight. Stress was maintained by lifting and suspending the dead weight load. Stress was decreased by resting the weight on a tray and decreasing the spring tension to zero. Figures 1, 2, and 3, on Pages 5 and 6 show the equipment at work.

Fatigue data is reported herein as ultimate load in pounds per inch of attaching edge. Detailed results are given in Appendix IV, Page 36 through 55. Table 2 below shows a tabulated comparison of fatigue results.

TABLE 2

TENSILE-FATIGUE AT AMBIENT TEMPERATURE (75°F. ± 5°F.)

SPECIMEN NUMBER	FATIGUE STRENGTH IN LBS. PER INCH OF ATTACHING EDGE AT: 1,000 Cycles	10,000 Cycles	100,000 Cycles	500,000 Cycles(Est)
STS-001A	825	645	485	420
STS-002	790	555	420	370
STS-003A	495	350	245	220
STS-004A	740	520	335	270
STS-005	405	345	300	300
STS-007	230	200	175	150
STS-008	500	450	410	380
STS-009	415	340	265	210
STS-010	530	360	320	310
STS-012	590	425	330	310
STS-013	680	460	365	340
STS-014A	790	575	450	420
STS-015	760	525	360	320
STS-022	850	650	560	540
STS-023	740	585	450	410

Several conclusions emerge from the fatigue data as evolved. All rigid attachments show a steep decline of fatigue strength. Nylon attachments STS-005, STS-007, STS-008, and STS-009, though they do not have a high initial strength, show a very flat fatigue decline as compared to the rigid designs. Fiberglas-acrylic attaching edges to MIL-P-6886 acrylic sheet in general show a typical slope of loss and appear to approach an endurance limit of approximately 300 lbs. per inch of width. Since all specimens are designed on either .312" thick monolithic sheet or .300" acrylic sheet in one half inch laminated stock this value seems to approach 1 pound per mil thickness of the transparent sheet.

For identical designs and a difference only in the acrylic sheet a rather interesting comparison can be made between STS-001A and STS-002, (MIL-P-6886) and their equivalents, STS-022 and STS-023 (MIL-P-5425). Initial strengths are somewhat at variance but fatigue strength at 1,000 cycles and again at 10,000 cycles

are almost identical for the monolithic designs (STS-001A and STS-022) and for the laminated designs (STS-002 and STS-023). However, beyond this point MIL-P-5425 sheet shows definitely super characteristics.

Tensile-fatigue tests were started at -65°F. on specimens STS-001A, STS-002, and STS-003. Results showed an amazing similarity between room temperature and depressed temperature data, with the cold temperature fatigue essentially strengths parallel to, but higher than the room temperature fatigue strengths (Figure 31, Page 38, Figure 33, Page 40 and Figure 35, Page 42).

It was decided that should this be the case all the way through, further pursuit along this line would not be worth the relatively great amount of time and effort involved, particularily in view of the fact that the information evolved would be of little or no value insofar as edge attachment designs is concerned.

To prove this apparent relation it was decided to pick a design where cold temperature ultimate tensile strength was materially less than room temperature tensile. STS-013 seemed to fit this description nicely since it shows a 21.5% loss in tensile strength at -65°F. (Table 1, Page 2).

Tensile-fatigue data as developed on STS-013 (Figure 44, Page 51) shows the fatigue strengths at room temperature and at -65°F. equal at approximately 40 cycles, and the predicted relation of higher values at cold temperatures thereafter. This probably indicates an unbalanced condition of internal stress in this design at depressed temperatures.

Cold fatigue work was discontinued at this point for the reasons outlined above.

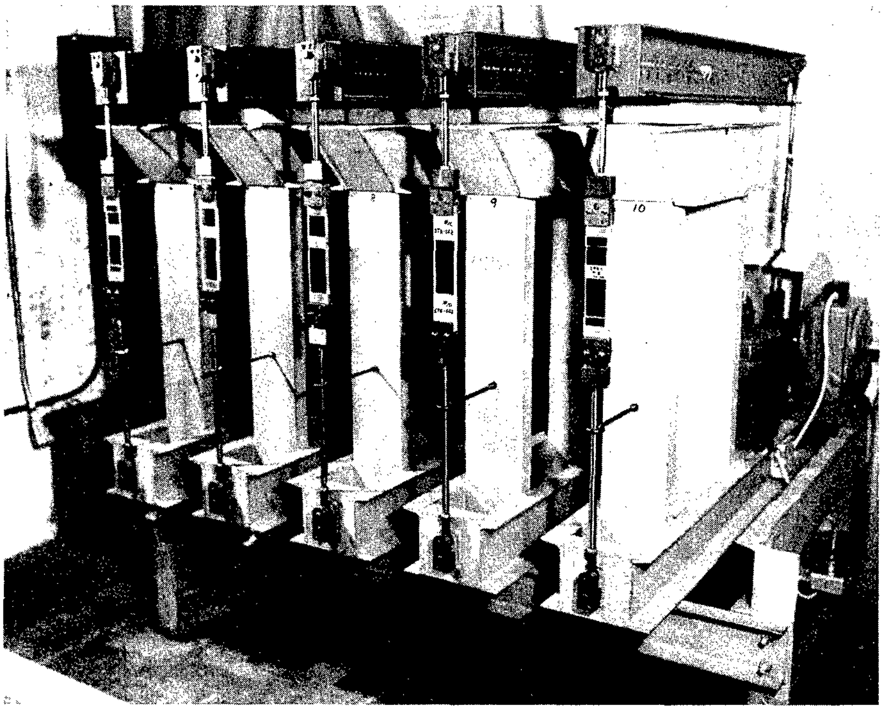


Figure 1. Tensile-fatigue units six to ten showing specimens in test position in the specimens grips.

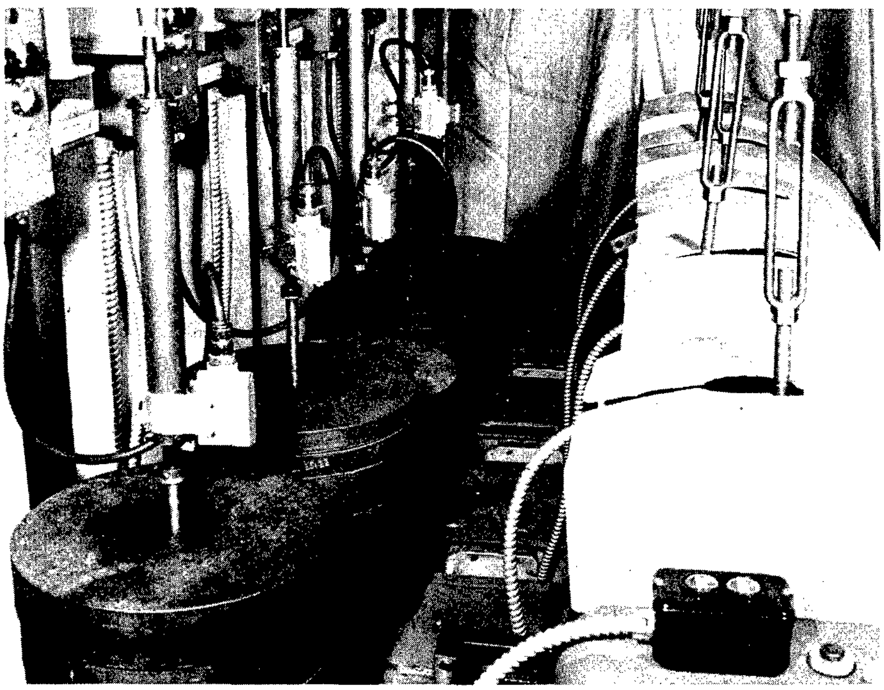


Figure 2. The operating and control end of the tensile-fatigue unit six to ten showing dead weight loads and rock arm assembly.

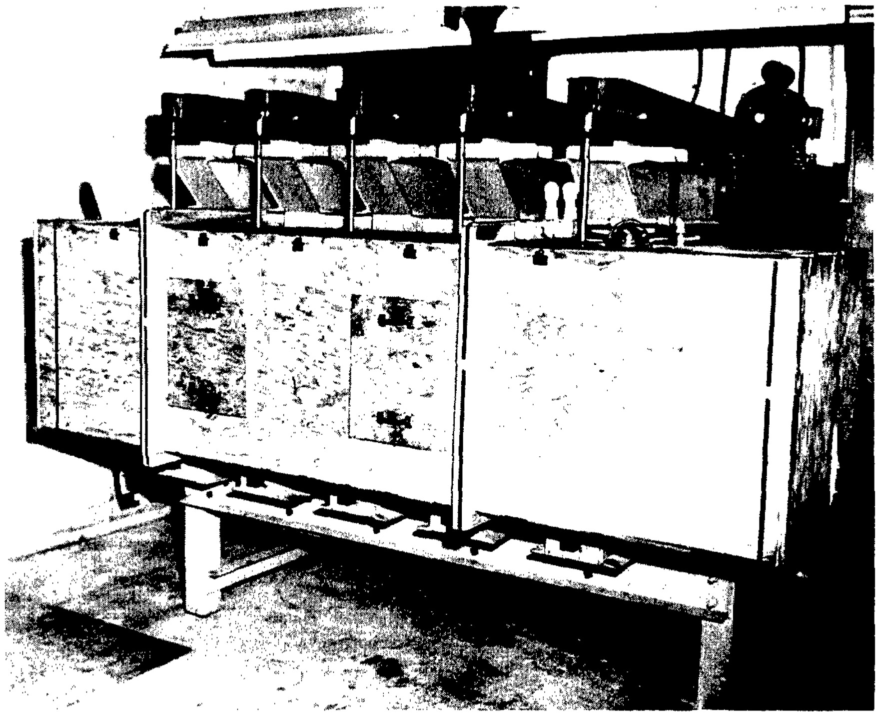


Figure 3. Tensile-fatigue units one to five showing cold chamber.

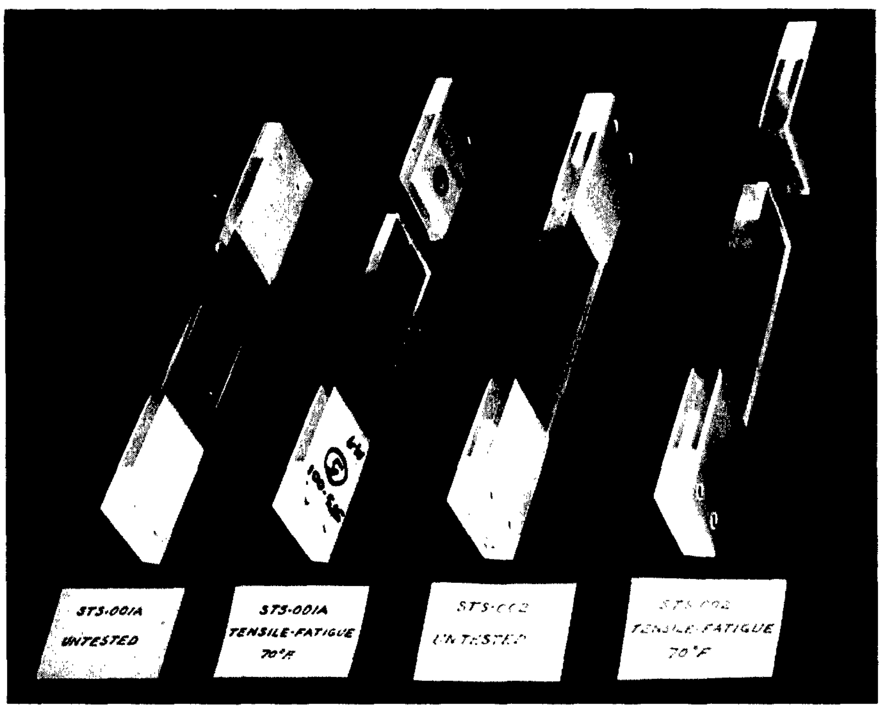


Figure 4. Test specimens.

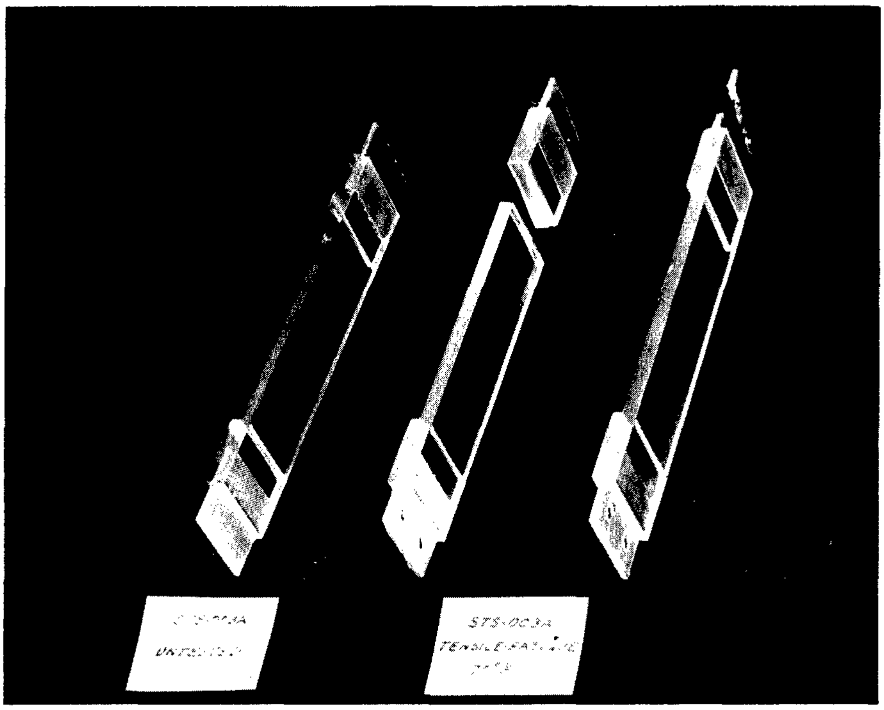


Figure 5. Test Specimens.

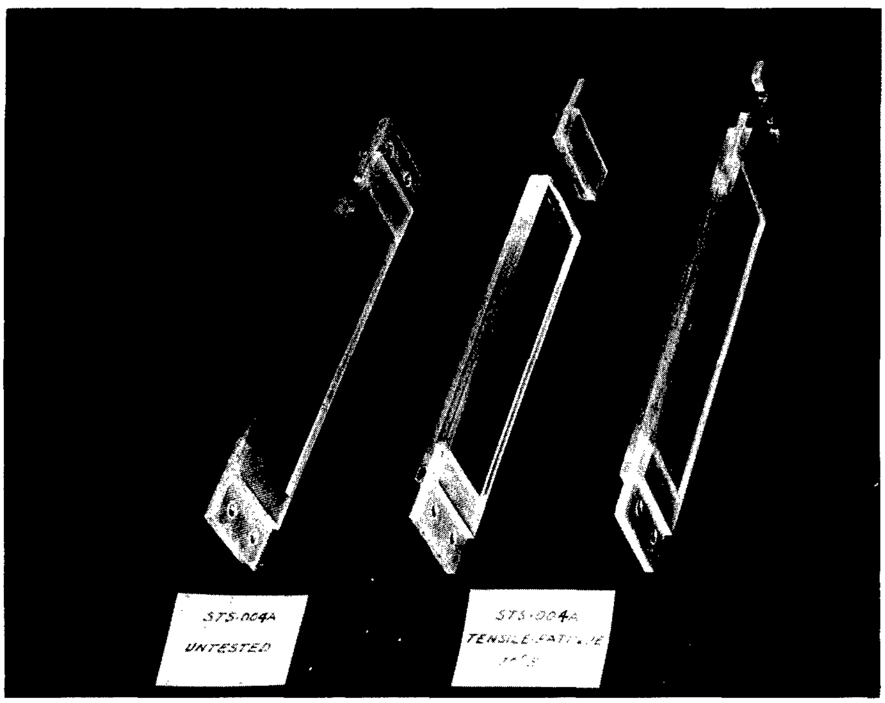


Figure 6. Test Specimens.

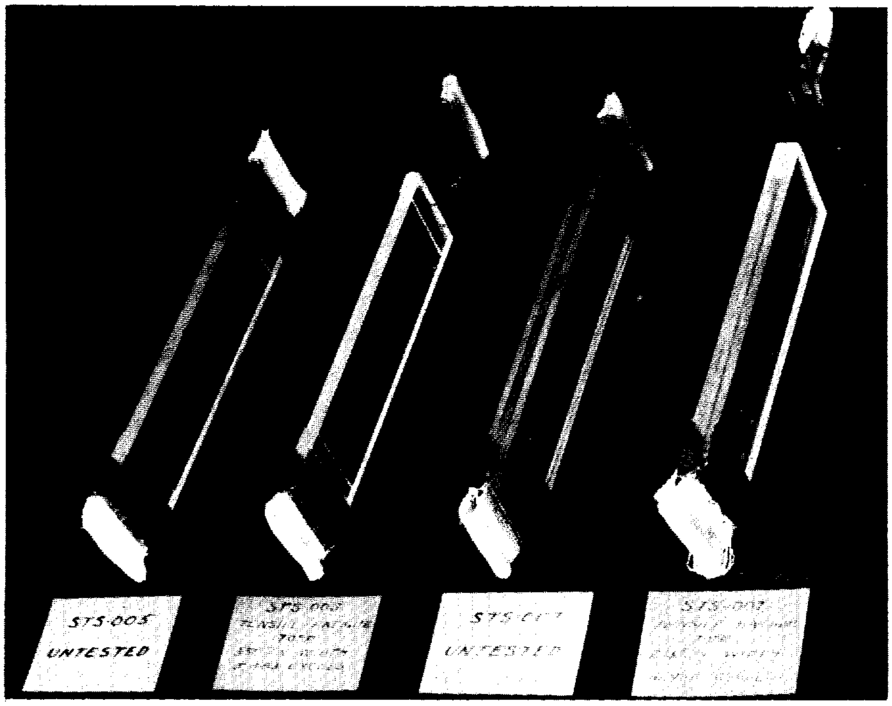


Figure 7. Test Specimens.

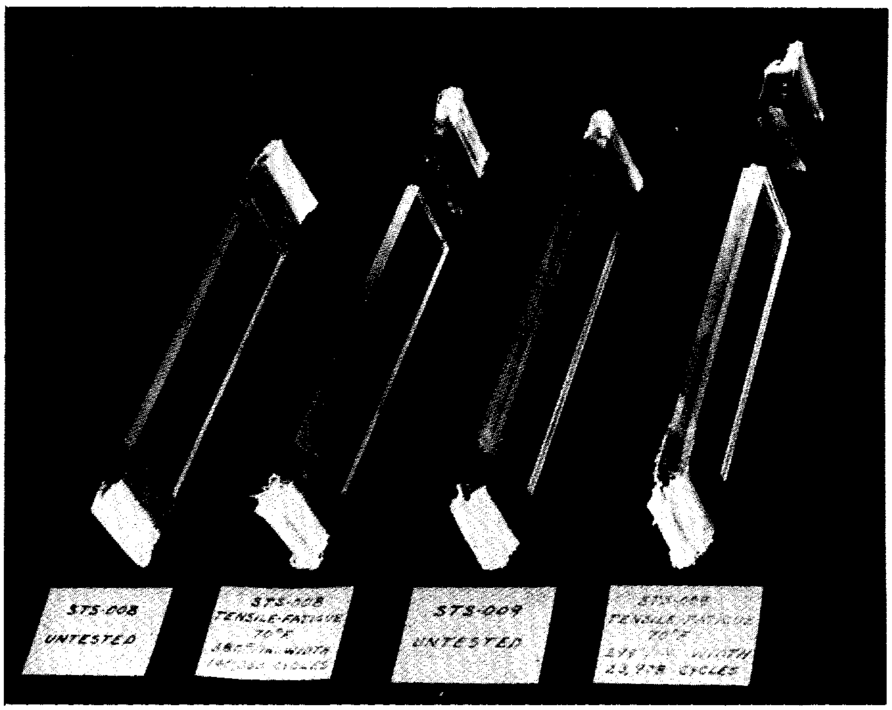


Figure 8. Test Specimens.

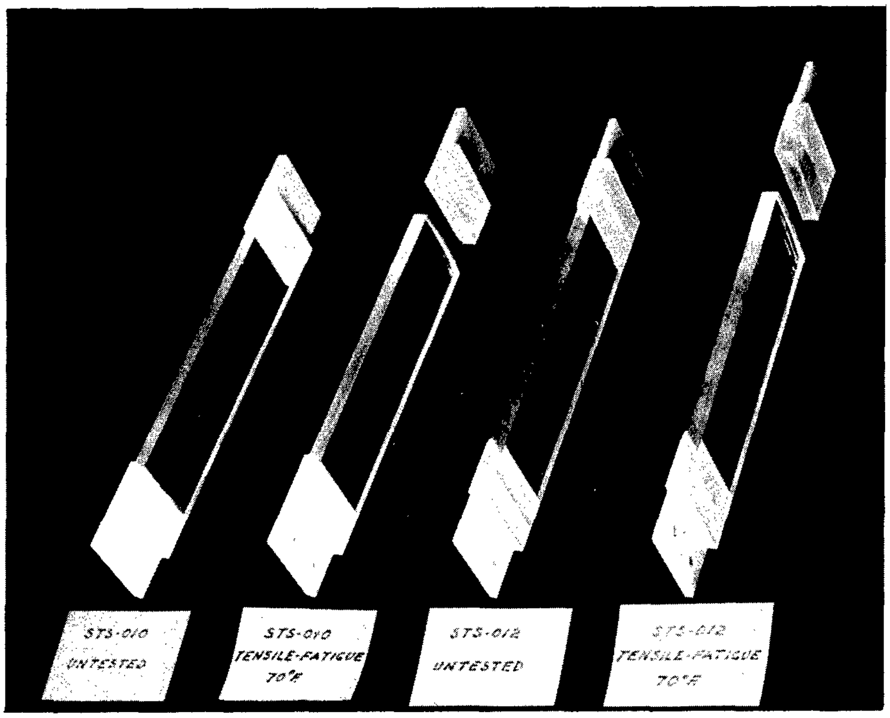


Figure 9. Test Specimens.

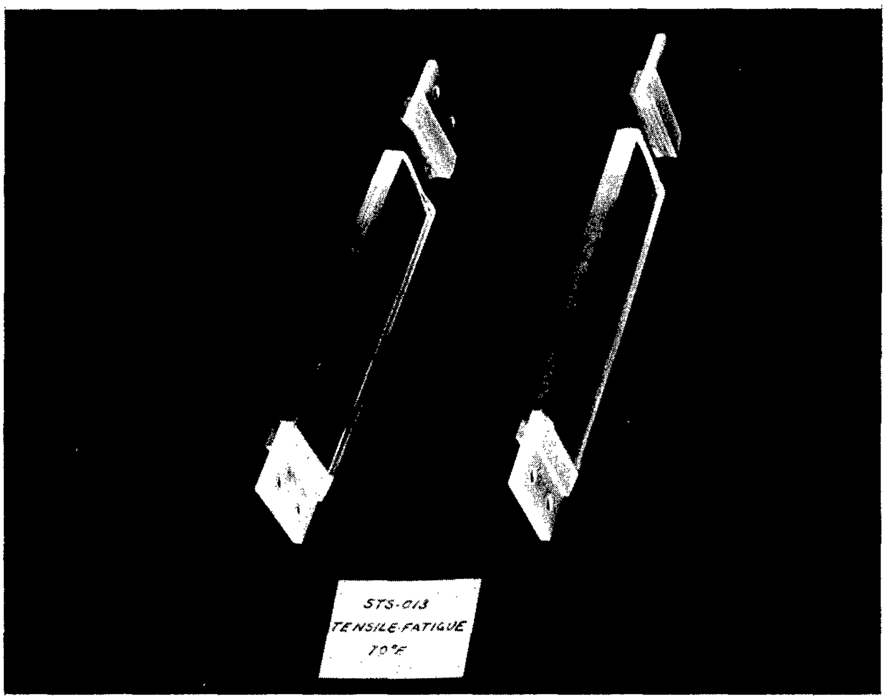


Figure 10. Test Specimens.

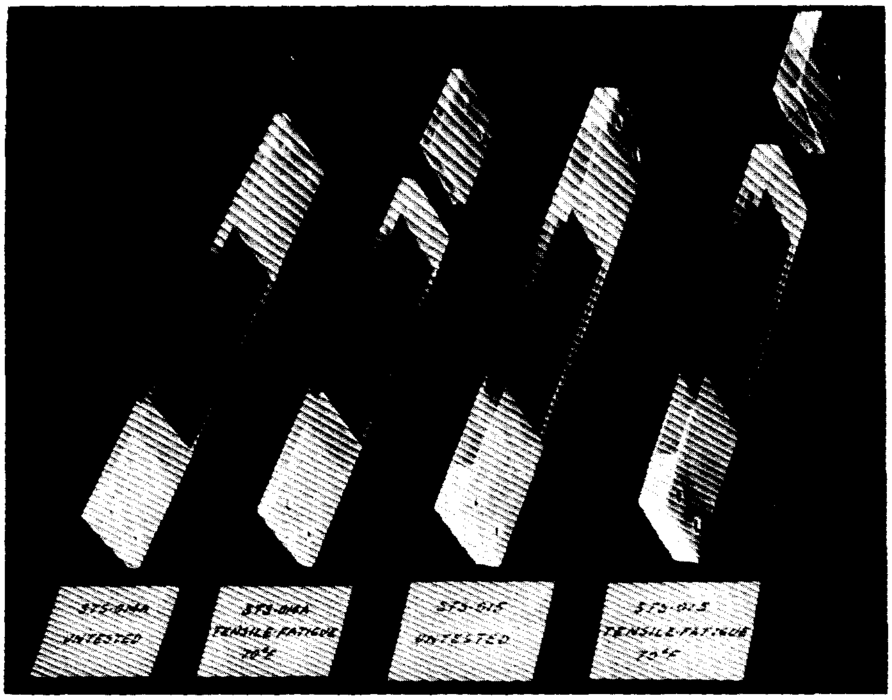


Figure 11. Test Specimens.

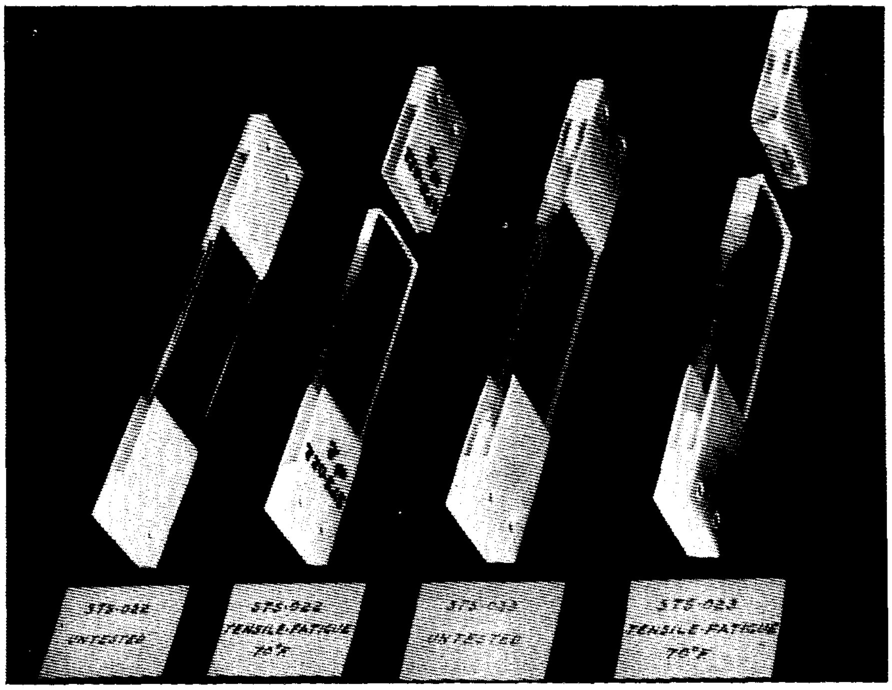


Figure 12. Test Specimens.

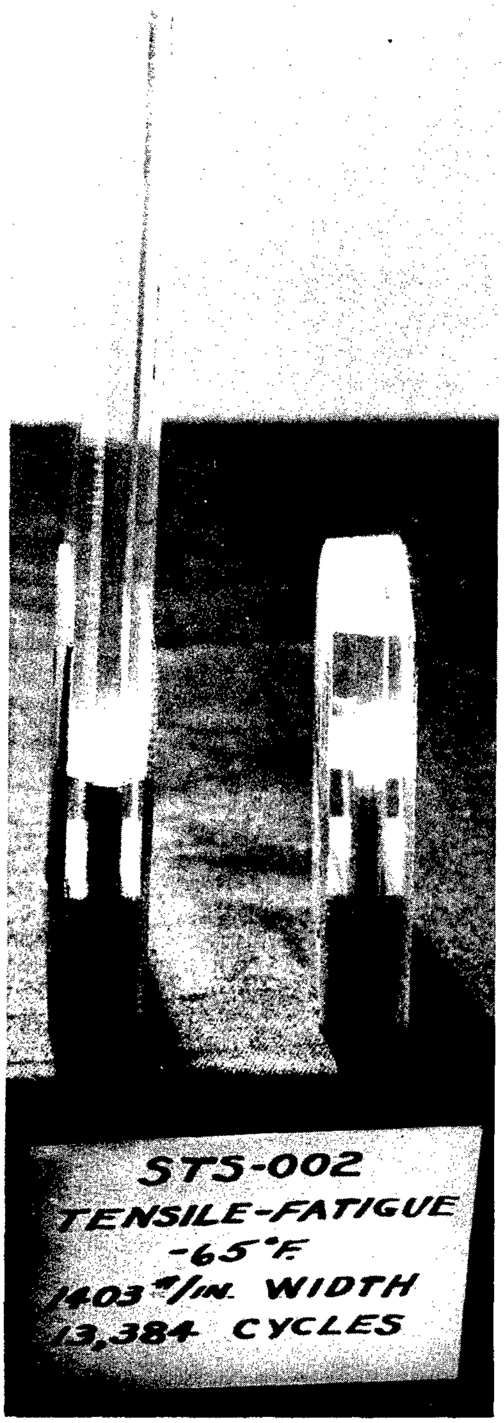


Figure 13.

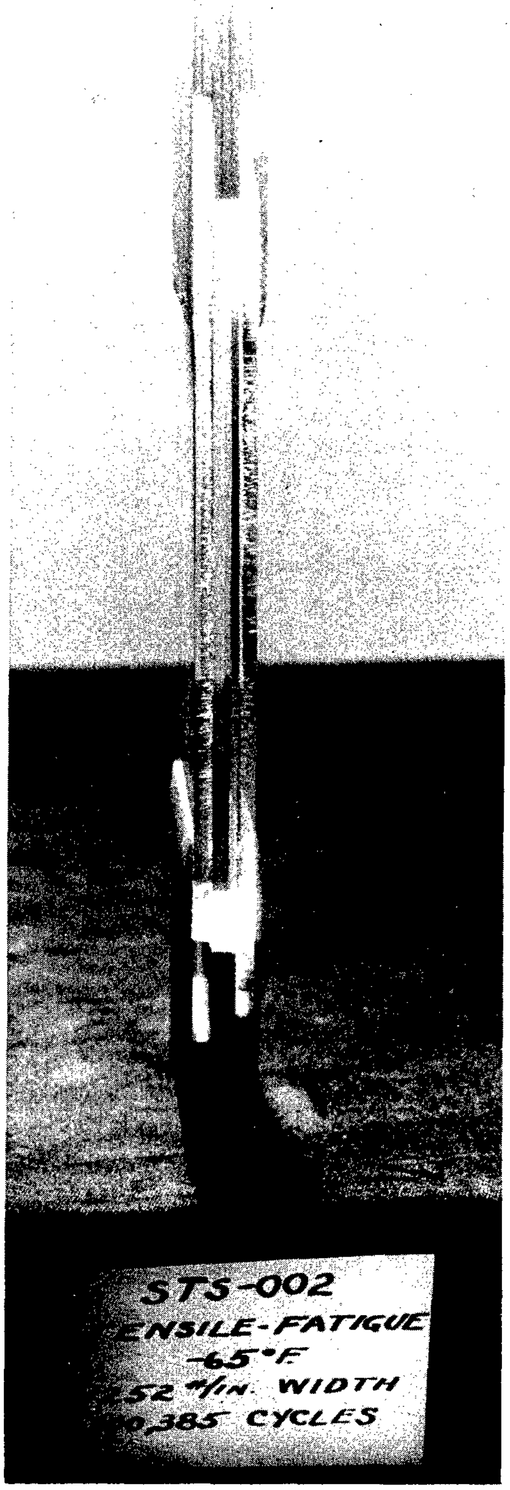


Figure 14.

Figure 13 and Figure 14 show typical fatigue fracture and craze originating from the butyral layer after long cycling at relatively high loads for laminated specimens.

APPENDIX I

MATERIAL SPECIFICATIONS

Monolithic cast acrylic sheet per specification MIL-P-6886 (.312"; 1/16"; 3/16").
Source: Rohm & Haas, Knoxville, Tennessee.

Monolithic cast acrylic sheet per specification MIL-P-5425, (.312").
Source: Rohm & Haas, Knoxville, Tennessee.

Laminated cast acrylic sheet per BMS 8-4 (.50"). Surface sheets .15" Polyvinyl butyral innerlayer sheet .20".
Source: Pittsburgh Plate Glass Company, Creighton, Penna.

Laminated cast acrylic sheet per BMS 8-4 (.50") with the exception that the surface sheets conform to specification MIL-P-5425. Surface sheets .15". Polyvinyl butyral innerlayer sheet .20".
Source: Pittsburgh Plate Glass Company, Creighton, Penna.

Fiberglas fabric, X-27-14 (Owens-Corning, finish 14).
Source: Coast Manufacturing Company, Livermore, California.
Physical characteristics:
- Plain weave
- 17 x 17
- Yarn, 150 3/3
- Thickness, .016"
- Minimum Breaking Strength, Warp, 375 lbs/sq. inch.
- Minimum Breaking Strength, Fill, 375 lbs/sq. inch.
- Weight, 12.73 oz/sq. yard.

Fiberglas fabric, ECC-11-128-14 (Owens-Corning, finish 14).
Source: Coast Manufacturing Company, Livermore, California.
Physical characteristics:
- Plain weave
- 42 x 32
- Yarn, 225 1/3
- Thickness, .007"
- Minimum Breaking Strength, Warp, 250 lbs/sq. inch.
- Minimum Breaking Strength, Fill, 200 lbs/sq. inch.
- Weight, 6.07 oz/sq. yard.

Stainless steel 30 mesh wire, 0.013" thickness.
Source: The Ludlow-Saylor Wire Company, St. Louis, Missouri.

Finished Nylon Duck, SN-5.
Source: Wellington Sears, Shawmut, Alabama.
Physical characteristics:
- 3 x 4 basket weave
- 58 1/2 x 58
- Thickness, .0375"
- Maximum Breaking Strength, Warp, 1169 lbs/sq. inch.
- Maximum Breaking Strength, Fill, 1177 lbs/sq. inch.
- Weight, 18.30 oz/sq. yard.

Fiberglas - Acrylic Laminate.
Source: Manufactured by Swedlow Plastics Company, 6986 Bandini Boulevard, Los Angeles 22, California, as press cured acrylic resin bonded Fiberglas laminate.

Stainless Steel Mesh - Acrylic Laminate.
Source: Manufactured by Swedlow Plastics Company, Los Angeles, California, as press cured acrylic resin bonded stainless steel mesh (Ludlow-Saylor Wire Company).

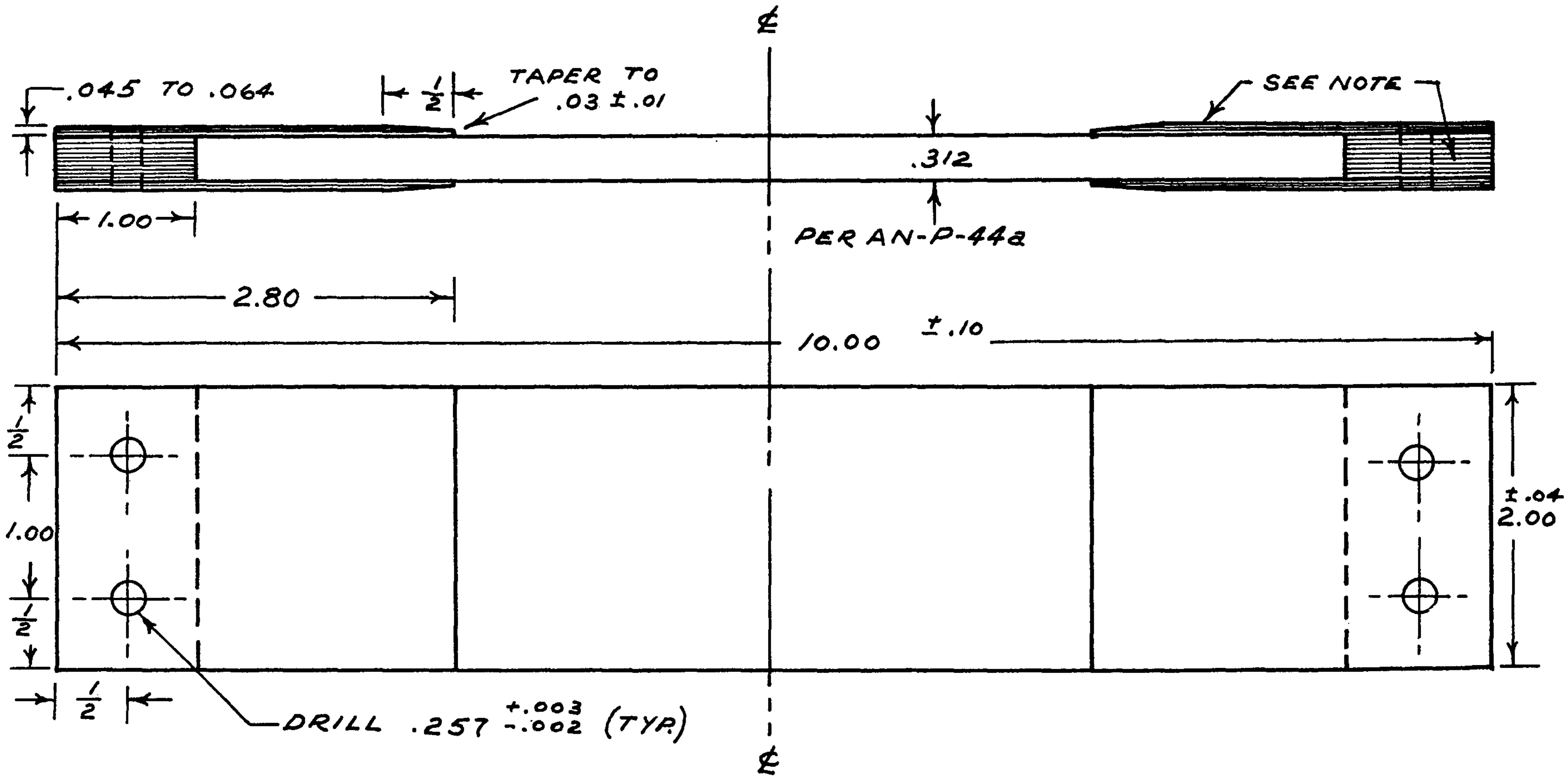
S-33 Precoating cement.
Source: Swedlow Plastics Company, Los Angeles, California
Characteristics:
Methylmethacrylate polymer thickened chlorinated solvent cement.

S-47-BS Cement.
Source: Swedlow Plastics Company, Los Angeles, California
Characteristics:
Totally reactive thickened methylmethacrylate syrup catalyzed to induce polymerization either by ultraviolet irradiation or by heat.

Penacolite XG-1500-2.
Source: Koppers Company, Inc., Chemical Division, Pittsburgh, Pa.

APPENDIX II

TRANSPARENT ENCLOSURE EDGE ATTACHMENT DESIGNS



NOTE:
X-27-14 ACRYLIC LAMINATE EARS & BUTT-BLOCK.

TOLERANCES:

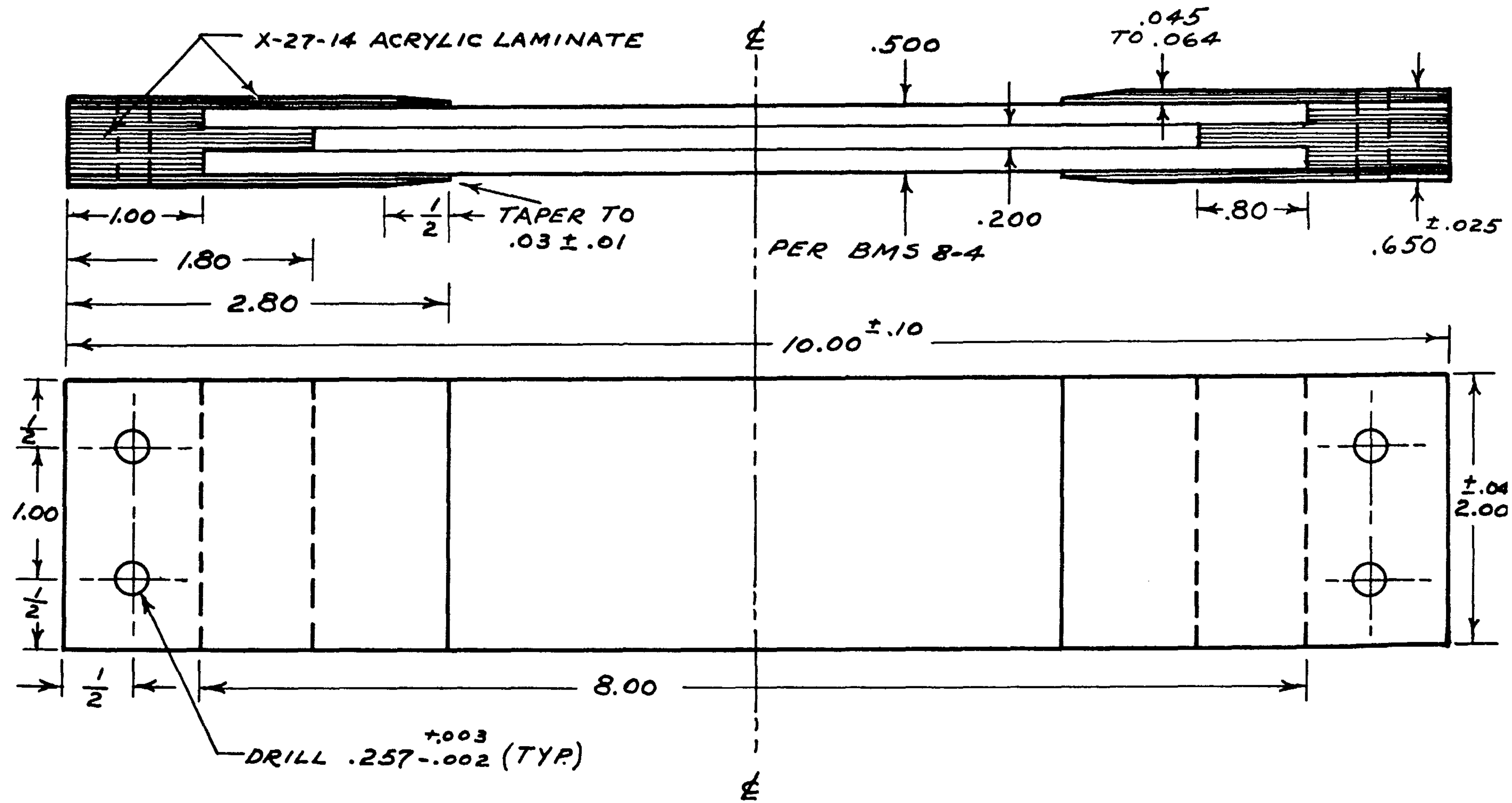
FRACTIONAL $\pm \frac{1}{32}$

DECIMAL .XX $\pm$ .030

.XXX $\pm$ .010

B-47 TYPE EDGE ATTACHMENT-MONOLITHIC		
STS-001A	SCALE: FULL	
DRAWN	R.D.LIGGETT	5/15/51
CHECKED	F. Norris	6/13/51
APPROVED	[illegible signature]	6/13/51

Figure 15.



TOLERANCES:

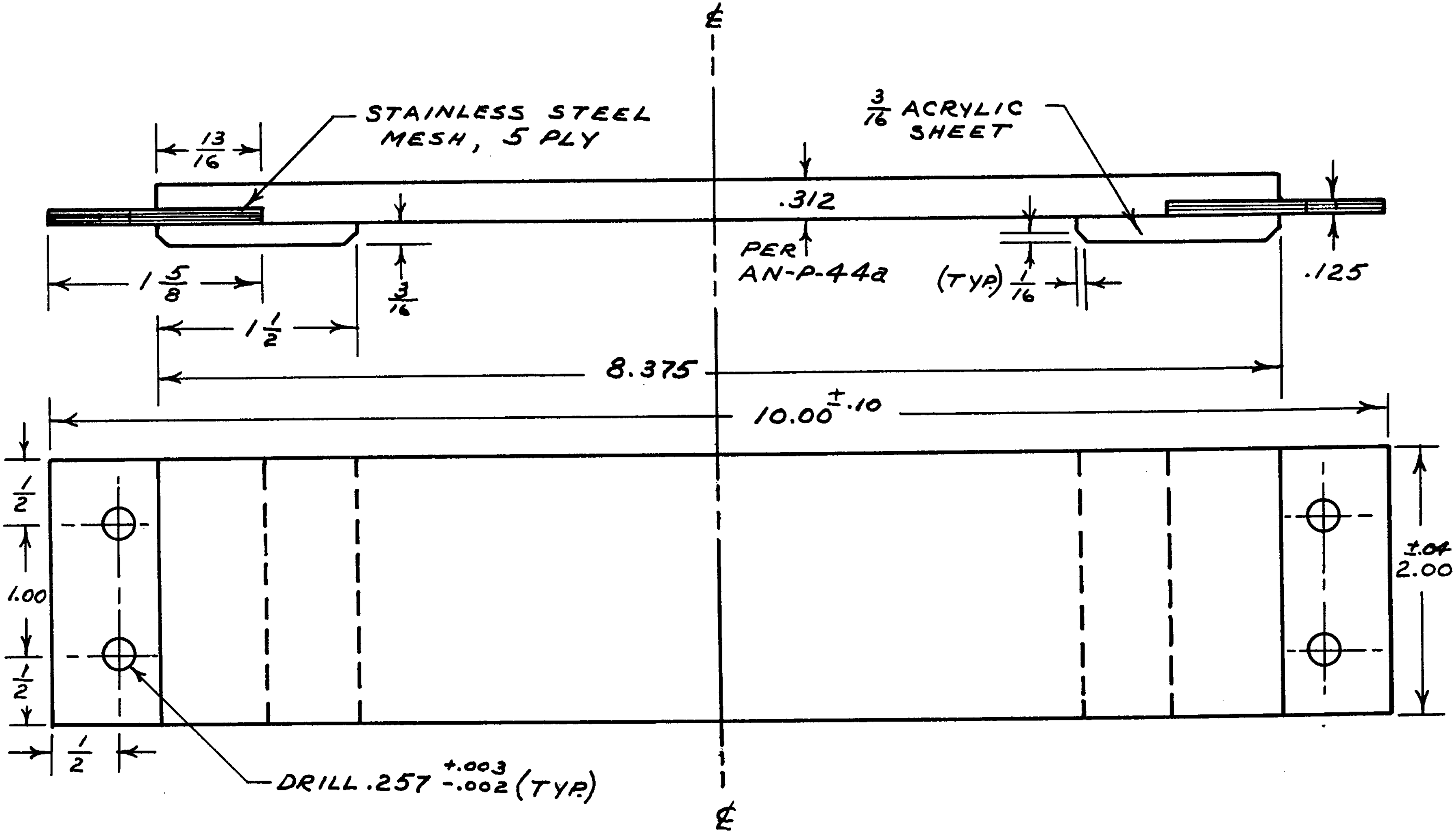
FRACTIONAL ± 1/32

DECIMAL .XX ± .030

.XXX ± .010

Figure 16.

B-47 TYPE EDGE ATTACHMENT-LAMINATED		
STS-002	SCALE: FULL	
DRAWN	R.D. LIGGETT	5/19/51
CHECKED	J. Norris	6/13/51
APPROVED	Elb Latham	6/13/51



TOLERANCES:

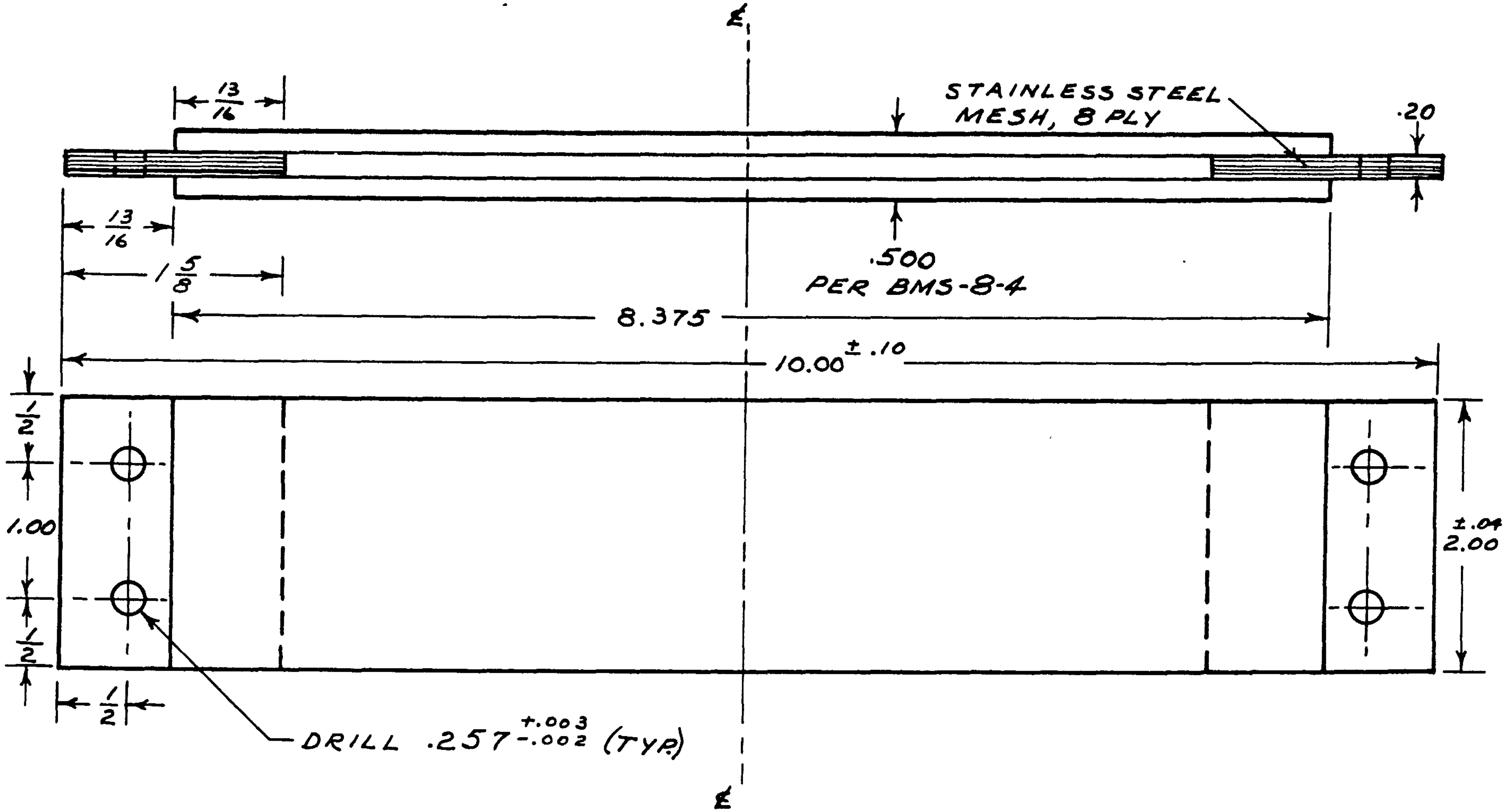
FRACTIONAL $\pm \frac{1}{32}$

DECIMAL .XX $\pm$.030

.XXX $\pm$.010

F-84-E TYPE EDGE ATTACHMENT-MONOLITHIC		
STS-003A	SCALE FULL	
DRAWN	R. D. LIGGETT	5/25/51
CHECKED	J. Noyes	6/13/51
APPROVED	Elb Latham	6/13/51

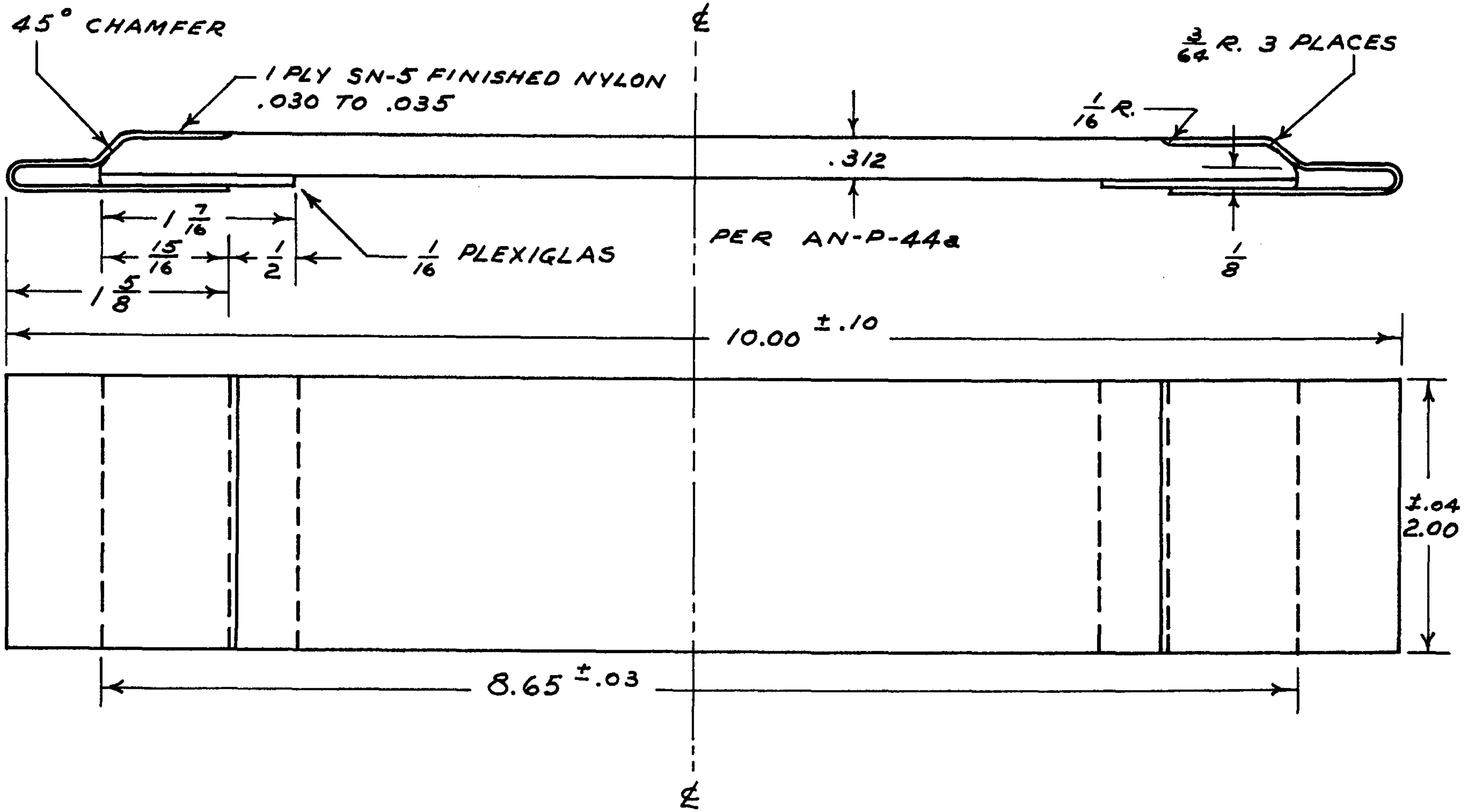
Figure 17.



TOLERANCES:
FRACTIONAL $\pm \frac{1}{32}$
DECIMAL .XX $\pm$ .030
.XXX $\pm$ .010

F-84-E TYPE EDGE ATTACHMENT-LAMINATED		
STS-004A	SCALE: FULL	
DRAWN	R.D. LIGGETT	5/28/51
CHECKED	[illegible]	6/13/51
APPROVED	[illegible]	6/13/51

Figure 18.



TOLERANCES:
FRACTIONAL $\pm \frac{1}{32}$
DECIMAL .XX ± .030
.XXX ± .010

F-86A TYPE EDGE
ATTACHMENT-MONOLITHIC
STS-005 SCALE: FULL

DRAWN	R. D. LIGGETT	5/16/51
CHECKED	J. Nognis	6/13/51
APPROVED	E.B. Latham	6/13/51

Figure 19.

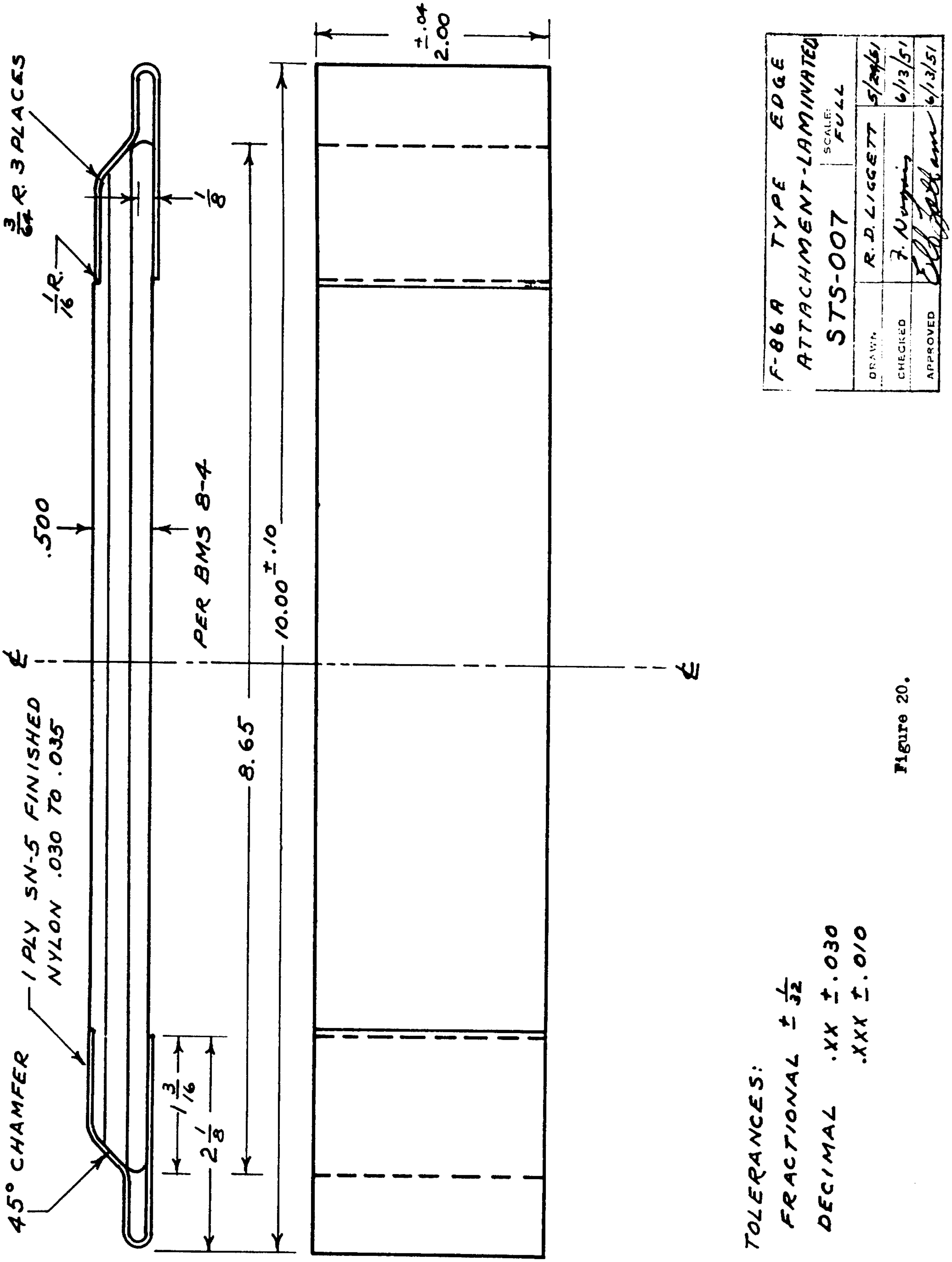
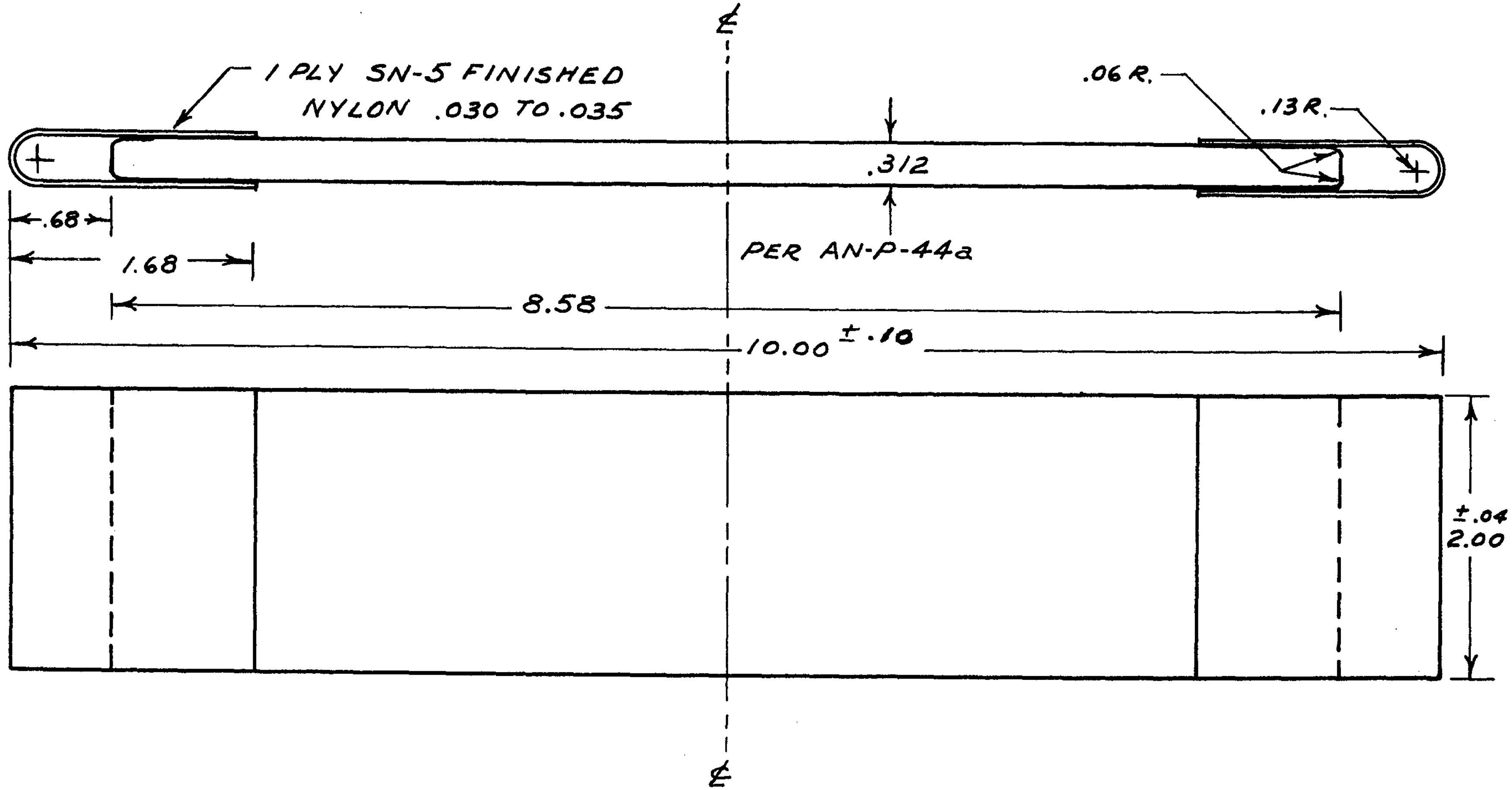

45° CHAMFER
1 PLY SN-5 FINISHED NYLON .030 TO .035
3/64 R. 3 PLACES
1/16 R.
1/8
.500
PER BMS 8-4
10.00 ± .10
8.65
2 1/8
1 3/16
± .04
2.00
F-86A TYPE EDGE
ATTACHMENT-LAMINATED
STS-007
SCALE: FULL
DRAWN R.D. LIGGETT 5/29/51
CHECKED 6/13/51
APPROVED 6/13/51
TOLERANCES:
FRACTIONAL ± 1/32
DECIMAL .XX ± .030
.XXX ± .010

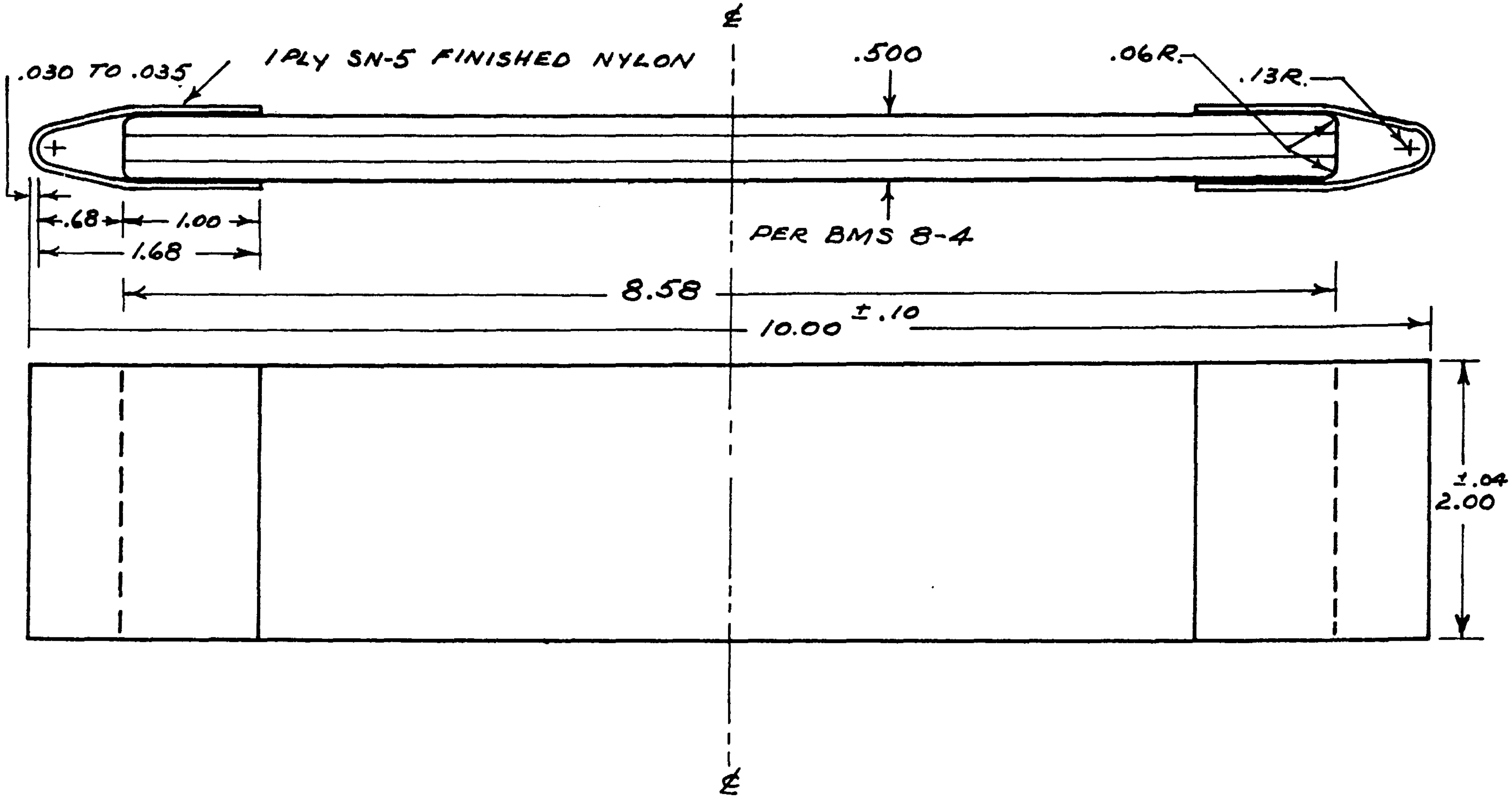
Figure 20.



TOLERANCES:
FRACTIONAL $\pm \frac{1}{32}$
DECIMAL .XX ± .030
.XXX ± .010

F-89 TYPE EDGE ATTACHMENT-MONOLITHIC		
STS-008	SCALE: FULL	
DRAWN	R. D. LIGGETT	5/18/51
CHECKED	F. Norris	6/13/51
APPROVED	E. B. Latham	6/13/51

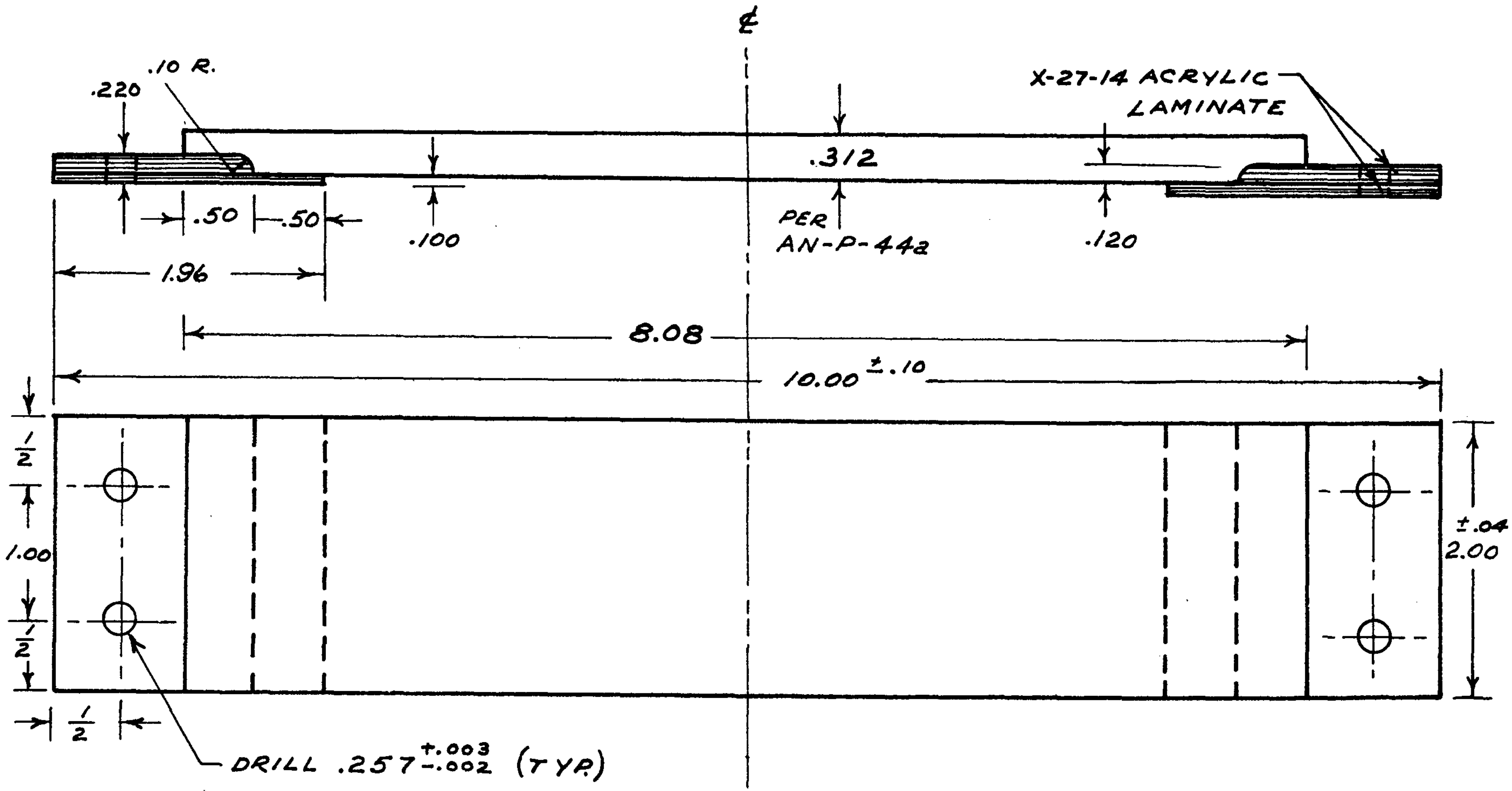
Figure 21.



TOLERANCES:
FRACTIONAL $\pm \frac{1}{32}$
DECIMAL .XX $\pm$.030
.XXX $\pm$.010

F-89 TYPE EDGE ATTACHMENT-LAMINATED STS-009	FULL	
DRAWN	R.D. LIGGETT	5/24/51
CHECKED	F. Norris	6/13/51
APPROVED	[illegible]	6/13/51

Figure 22.



TOLERANCES:

FRACTIONAL ± 1/32

DECIMAL .XX ± .030

.XXX ± .010

F-89A TYPE EDGE ATTACHMENT-MONOLITHIC		
STS-010	SCALE: FULL	
DRAWN	R. D. LIGGETT	5/26/51
CHECKED	F. Nopiis	6/11/51
APPROVED	Elb Latham	6/13/51

Figure 23.

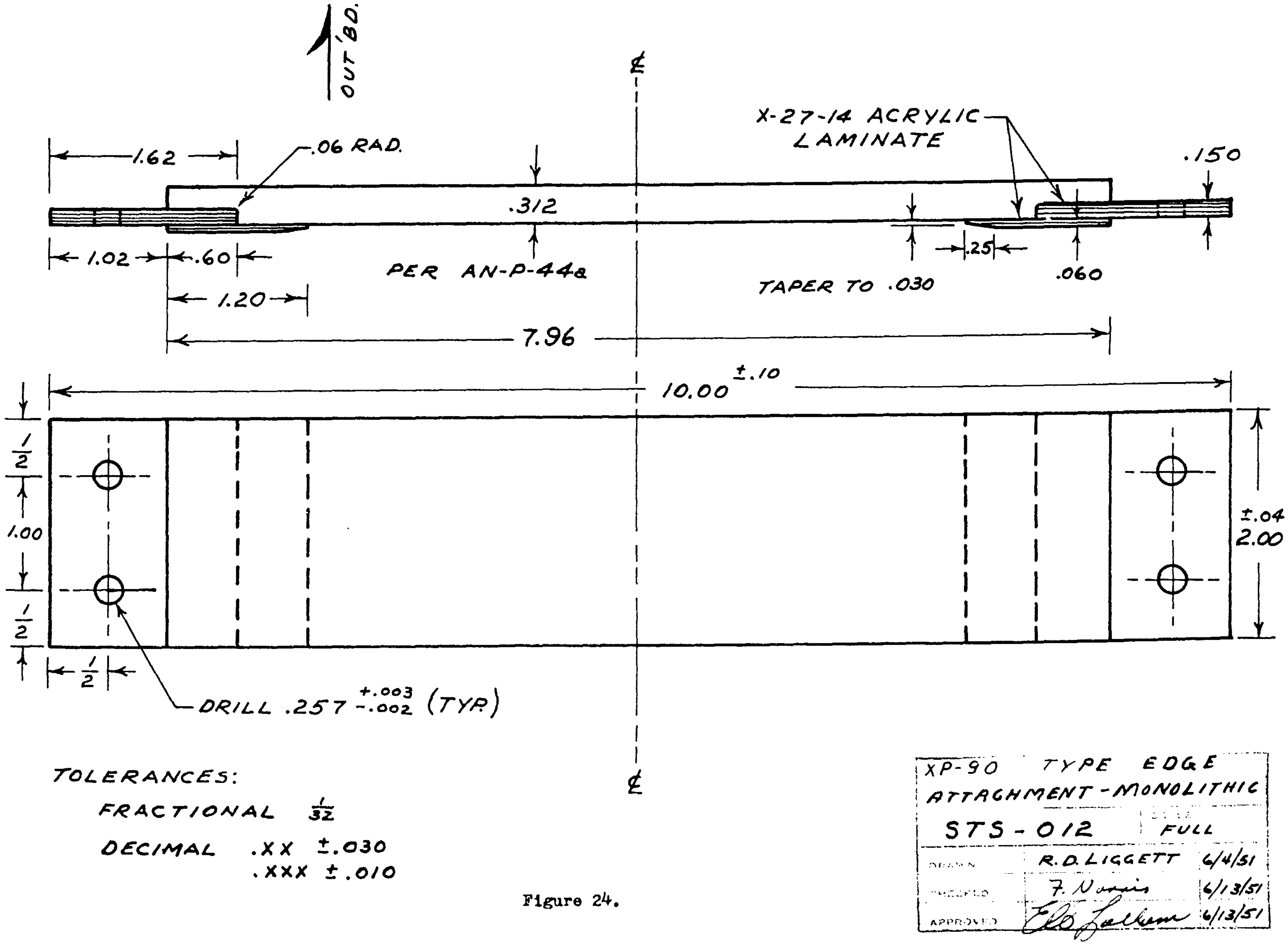
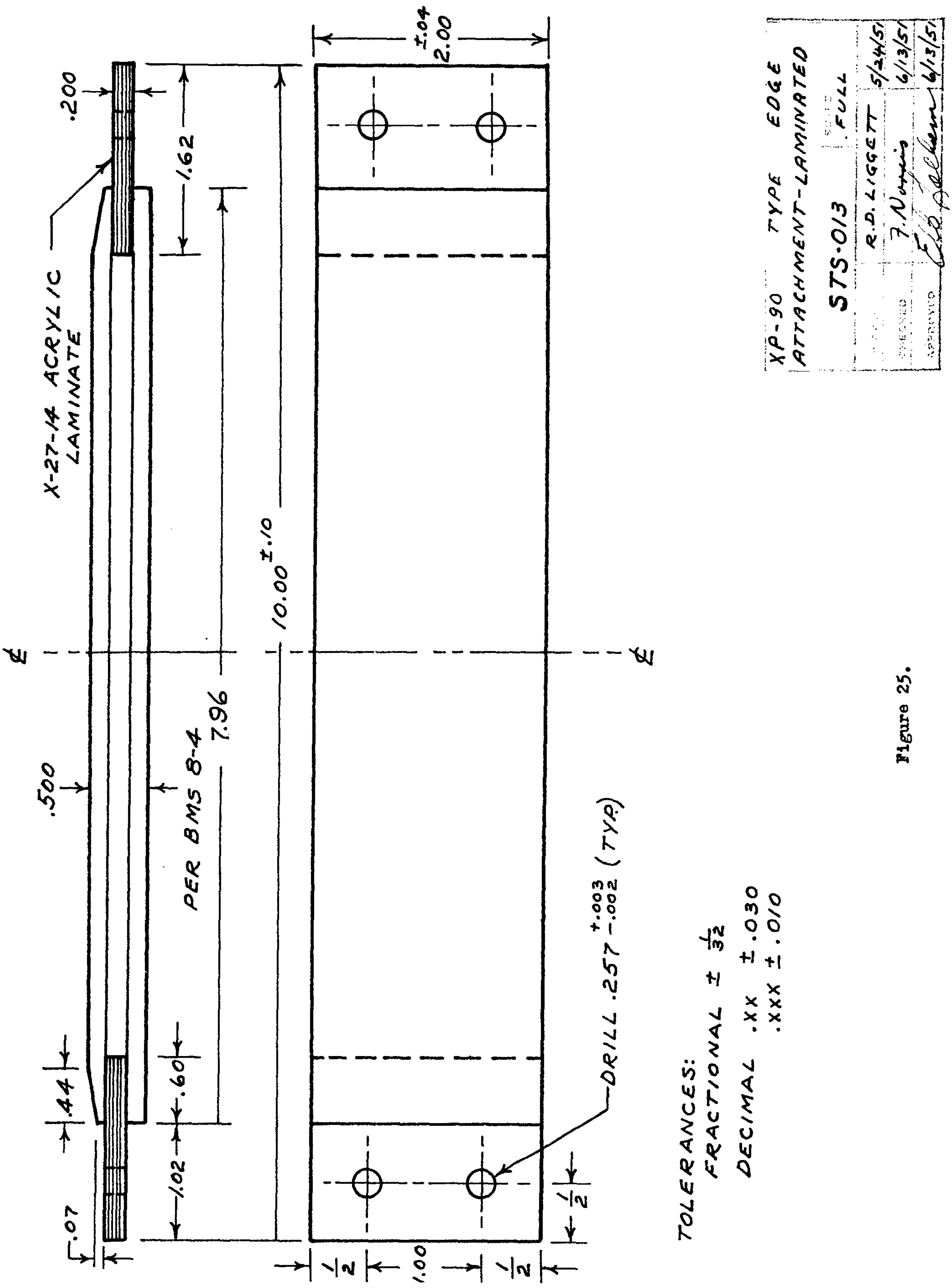
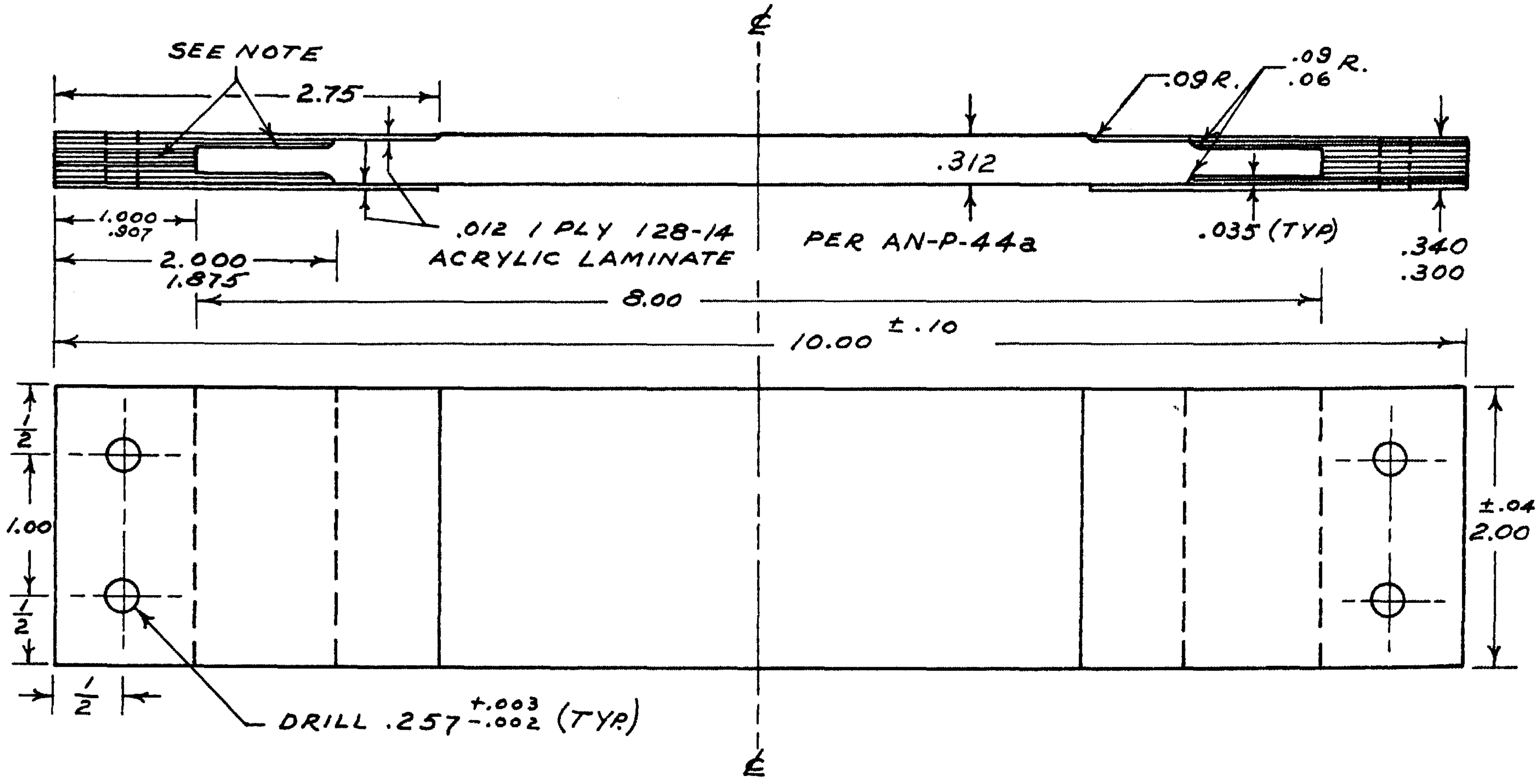

OUT'BD.
.06 RAD.
1.62
.312
X-27-14 ACRYLIC
LAMINATE
.150
1.02
.60
PER AN-P-44a
.25
.060
TAPER TO .030
1.20
7.96
10.00 ±.10
1/2
1.00
1/2
1/2
±.04
2.00
DRILL .257 +.003 -.002 (TYP)
TOLERANCES:
FRACTIONAL 1/32
DECIMAL .XX ±.030
.XXX ±.010
XP-90 TYPE EDGE
ATTACHMENT-MONOLITHIC
STS-012
FULL
R.D.LIGGETT 6/4/51
6/13/51
APPROVED
6/13/51

Figure 24.



X-27-14 ACRYLIC LAMINATE
.200
1.62
.500
PER BMS 8-4
7.96
10.00 ±.10
2.00 ±.04
.44
.60
1.02
.07
1/2
1.00
1/2
1/2
DRILL .257 +.003 −.002 (TYP.)
TOLERANCES:
FRACTIONAL ± 1/32
DECIMAL .XX ±.030
.XXX ±.010
XP-90 TYPE EDGE ATTACHMENT-LAMINATED
STS-013
SCALE FULL
DRAWN R.D. LIGGETT 5/24/51
CHECKED 7. Norris 6/13/51
APPROVED 6/13/51

Figure 25.



NOTE:

EARS & BUTT-BLOCK TO BE X-27-14 ACRYLIC LAMINATE.

TOLERANCES:

FRACTIONAL $\pm \frac{1}{32}$

DECIMAL .XX ± .030
.XXX ± .010

Figure 26.

F-94 TYPE EDGE ATTACHMENT — MONOLITHIC		
STS-014A	FULL	
DRAWN	R.D. LIGGETT	5/15/51
CHECKED	F. Norris	6/13/51
APPROVED	[illegible signature]	6/13/51

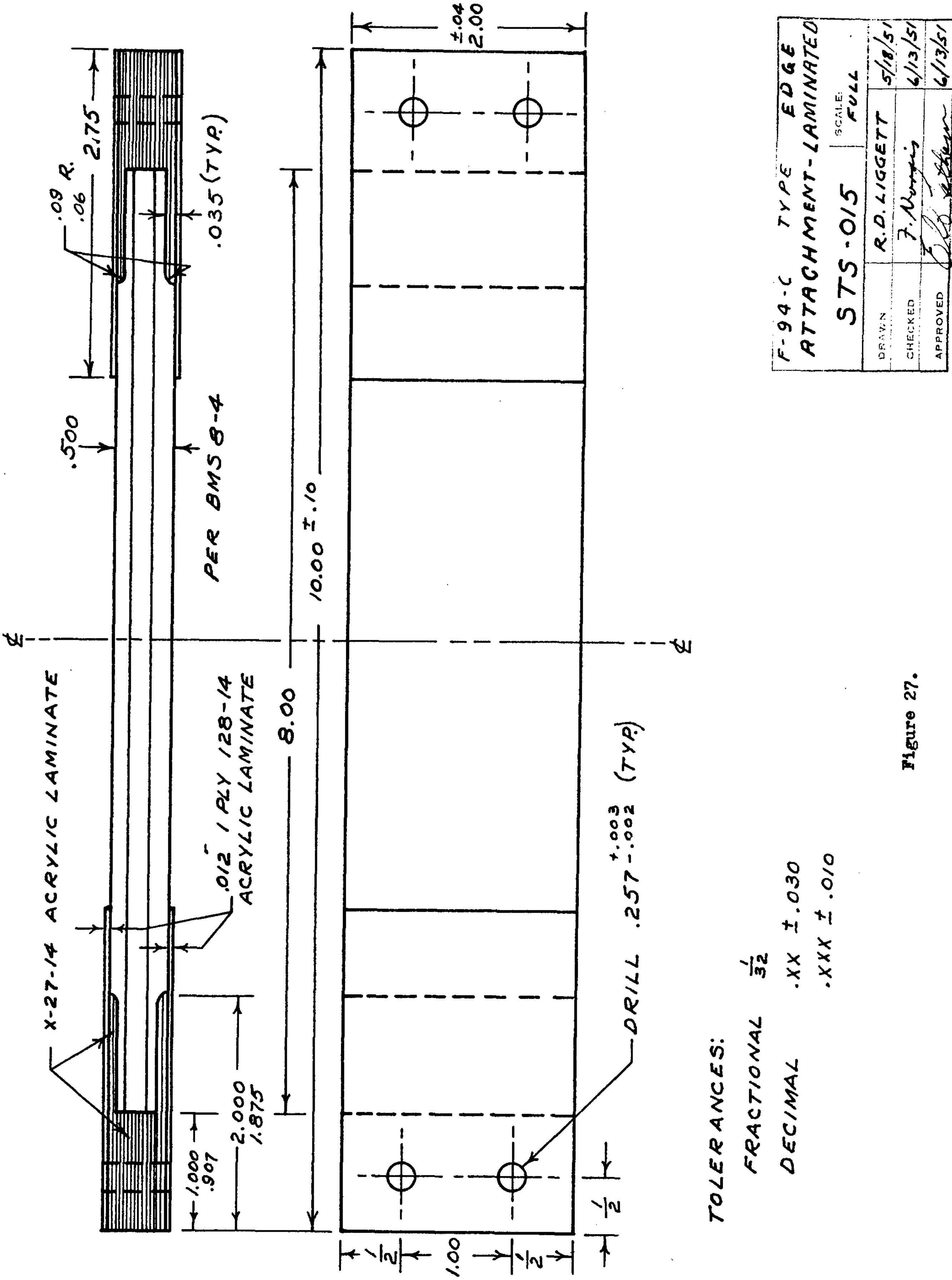

F-94-C TYPE EDGE
ATTACHMENT-LAMINATED
STS-015
SCALE: FULL
DRAWN R.D. LIGGETT 5/18/51
CHECKED 6/13/51
APPROVED 6/13/51
X-27-14 ACRYLIC LAMINATE
.09 R.
.06
2.75
.035 (TYP.)
.500
PER BMS 8-4
.012 1 PLY 128-14
ACRYLIC LAMINATE
1.000
.907
2.000
1.875
8.00
10.00 ± .10
2.00 ± .04
DRILL .257 +.003 -.002 (TYP.)
1/2
1.00
1/2
1/2
TOLERANCES:
FRACTIONAL 1/32
DECIMAL .XX ± .030
.XXX ± .010

Figure 27.

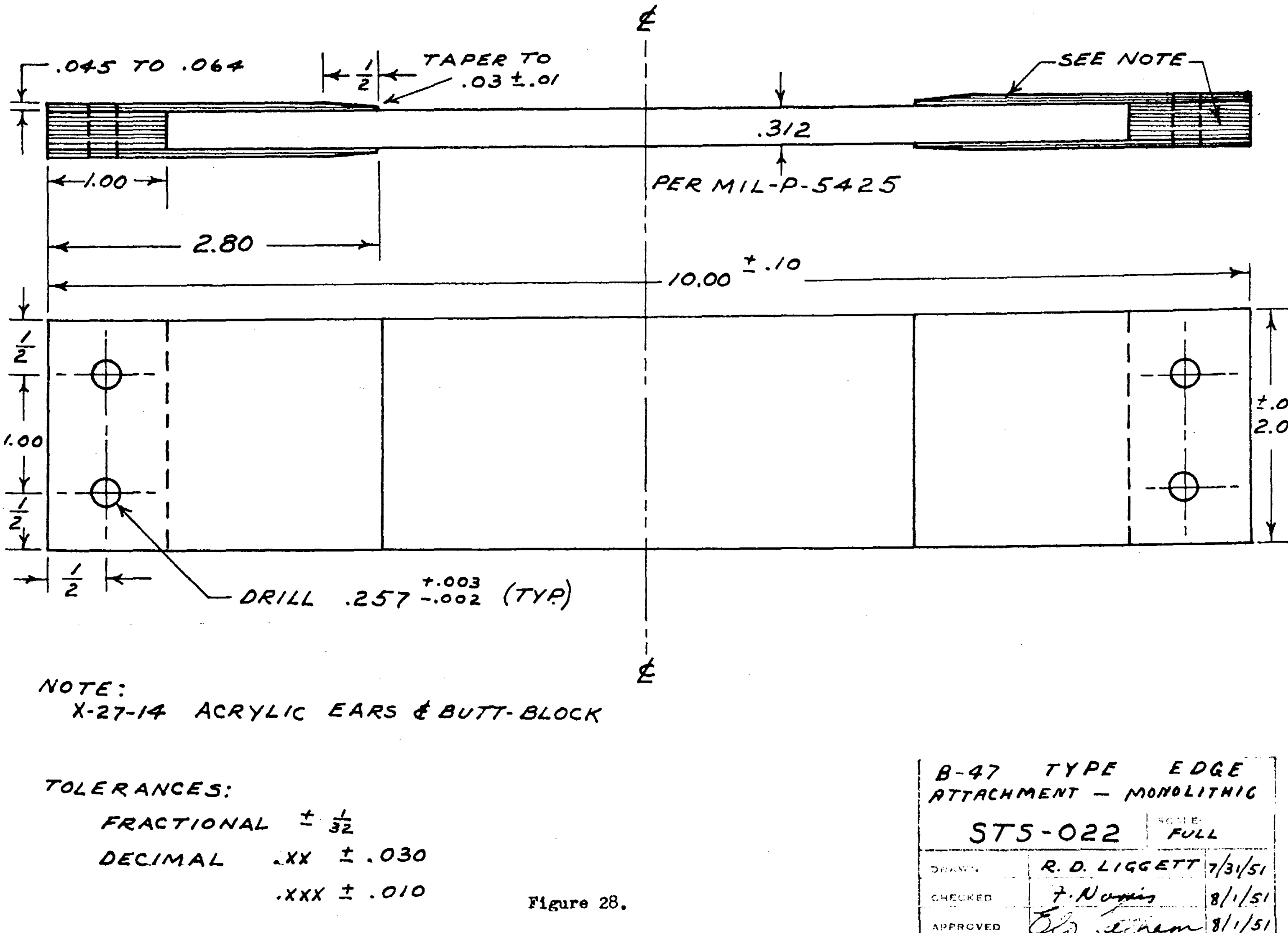

.045 TO .064
TAPER TO .03 ± .01
1/2
SEE NOTE
.312
PER MIL-P-5425
1.00
2.80
10.00 ± .10
1/2
1.00
1/2
1/2
DRILL .257 +.003 -.002 (TYP.)
2.00 ±.04
NOTE:
X-27-14 ACRYLIC EARS & BUTT-BLOCK
TOLERANCES:
FRACTIONAL ± 1/32
DECIMAL .XX ± .030
.XXX ± .010
B-47 TYPE EDGE ATTACHMENT — MONOLITHIC
STS-022
SCALE: FULL
DRAWN R. D. LIGGETT 7/31/51
CHECKED 8/1/51
APPROVED 8/1/51

Figure 28.

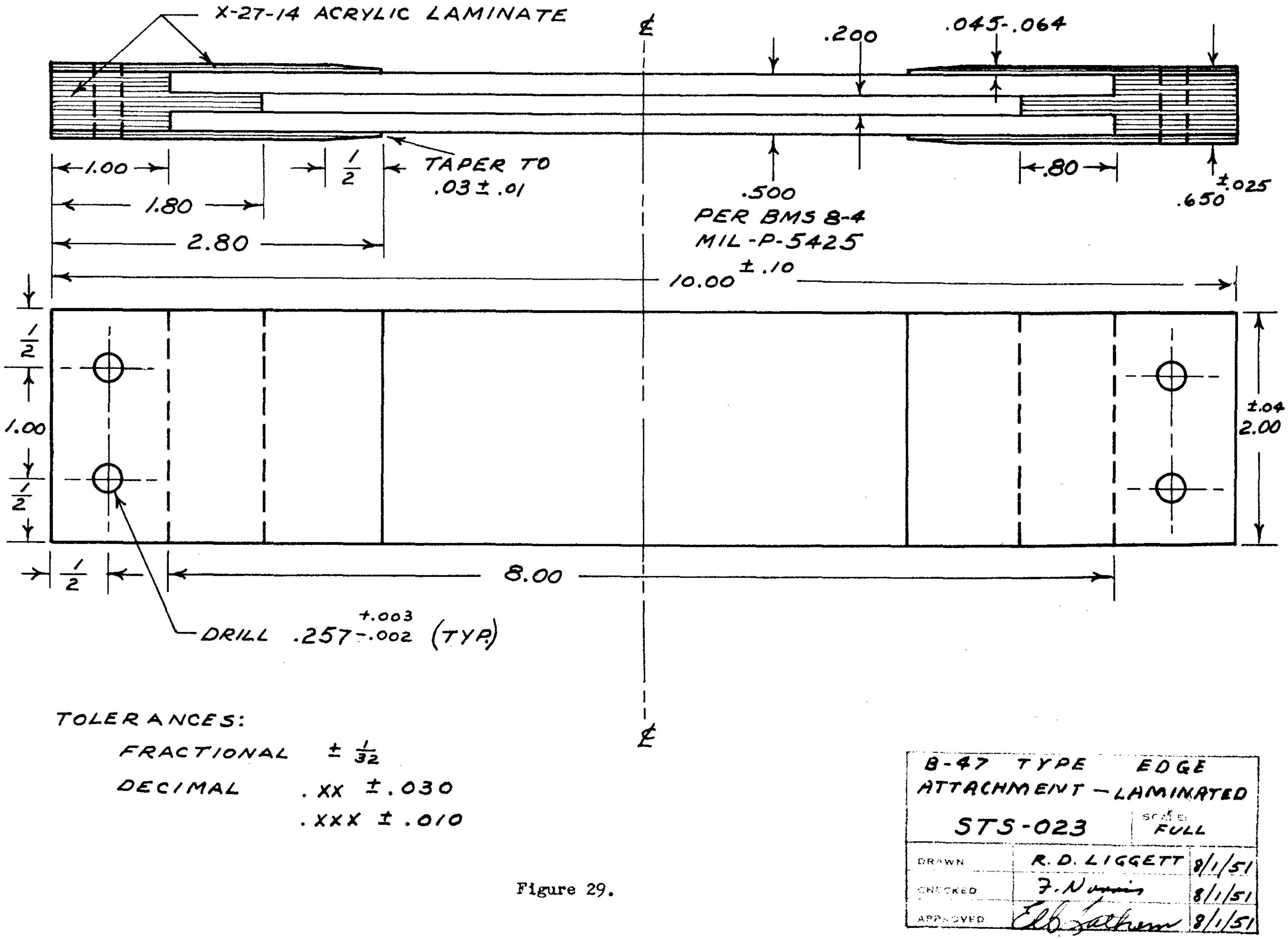

X-27-14 ACRYLIC LAMINATE
.200
.045-.064
1.00
1.80
2.80
1/2
TAPER TO .03 ± .01
.500 PER BMS 8-4 MIL-P-5425
.80
.650 ±.025
10.00 ±.10
1/2
1.00
1/2
±.04 2.00
1/2
8.00
DRILL .257 +.003 -.002 (TYP)
TOLERANCES:
FRACTIONAL ± 1/32
DECIMAL .XX ±.030
.XXX ±.010
B-47 TYPE EDGE ATTACHMENT - LAMINATED
STS-023
SCALE: FULL
DRAWN R. D. LIGGETT 8/1/51
CHECKED 8/1/51
APPROVED 8/1/51

Figure 29.

APPENDIX III

TENSILE TEST DETAILS

Tensile test performed at 70°F. ± 5°F. were conducted on a Dillon Tensile Tester, (Hercules Model K). This machine is operated with a mechanical power drive. The dynamometer indicator is calibrated regularly by the Los Angeles County Department of Weights and Measures using a dead weight method of calibration. Tensile tests performed at -65°F. + 0°F. -5°F. were conducted on a Baldwin Universal Tester maintained as commercial testing equipment by Triplett and Barton Incorporated, 831 No. Lake Street, Burbank, California.

In all cases the testing was conducted using a grip which roughly simulated actual frame installation. In the case of rigid attaching ends the specimen was tested in bearing on two 1/4" pins at each end. The Nylon loop type attachments were tested with the loop locked around a 1/4" lateral pin in a slot simulating frame installation.

Tensile test procedures were per ASTM D-628-49T and the rate of pull was .25" per minute.

In the following tabulated test results all specimens ruptured in the acrylic sheet at the inner edge of the attachment unless otherwise noted.

	--STS-001A (75°F)--				--STS-001A (-65°F)--			
Spec. No.	Width	Thick ness	Lbs. Pulled	Lbs/inch of Width	Width	Thick ness	Lbs. Pulled	Lbs/inch of Width
1	1.986	.309	3400	1715	2.003	.301	3175	1585
2	1.991	.295	3000	1505	2.000	.303	3260	1630
3	2.012	.301	2550	1268	1.997	.306	3795	1900
4	2.002	.300	2500	1250	1.999	.311	3560	1781
5	2.000	.300	2500	1250	2.008	.323	4265	2124
6	2.007	.298	2500	1243	2.006	.298	2915	1453
7	2.006	.302	2750	1370	2.012	.307	3415	1697
8	1.992	.306	2450	1230	2.008	.309	3565	1775
9	1.995	.323	3050	1530	2.014	.302	3180	1579
10	2.000	.311	2850	1425	2.006	.309	3515	1752
			Average	1379			Average	1728

	--STS-002 (75°F)--				--STS-002 (-65°F)--			
Spec. No.	Width	Thick-ness	Lbs. Pulled	Lbs/inch of Width	Width	Thick-ness	Lbs. Pulled	Lbs/inch of Width
1	2.004	.517	2750	1370	2.003	.526	4515	2254
2	2.000	.517	3500	1750	2.004	.521	3825	1909
3	2.006	.516	4000	1990	2.003	.531	4400	2197
4	2.009	.510	4600	2290	2.003	.522	5035	2514
5	2.004	.520	3150	1570	1.960	.515	4025	2054
6	2.008	.518	3100	1542	2.002	.523	4600	2298
7	1.985	.516	3695	1860	2.002	.531	3925	1961
8	2.005	.514	3450	1720	2.002	.527	4050	2023
9	2.007	.516	3700	1840	2.001	.515	4480	2239
10	2.000	.515	3550	1775	2.001	.531	5130	2564
			Average	1771			Average	2201

	--STS-003A (75°F)--				--STS-003A (-65°F)--			
1	2.002	.314	1800	900	2.000	.311	2675	1338
2	2.008	.315	1650	823	2.007	.315	2415	1203
3	2.005	.318	1850	922	2.009	.325	1990	991
4	2.010	.319	1650	820	2.009	.325	1700	846
5	2.007	.316	1700	848	2.013	.309	2190	1088
6	2.006	.313	1850	921	2.006	.316	1820	907
7	2.007	.317	2050	1022	2.002	.326	1995	997
8	1.999	.313	1850	925	2.006	.321	1890	942
9	1.992	.306	1950	980	2.005	.319	1980	988
10	2.004	.318	1950	970	1.999	.315	1790	895
			Average	913			Average	1019

Specimen No.2 failed in bearing.

All specimens failed in bearing.

	--STS-004A (75°F)--				--STS-004A (-65°F)--			
1	2.011	.510	2700	1342	2.025	.517	2200	1086
2	2.004	.512	3050	1520	2.007	.513	3095	1542
3	2.002	.508	2850	1425	2.018	.519	2960	1467
4	2.004	.507	2350	1172	2.011	.510	2375	1181
5	2.004	.512	2950	1472	2.015	.517	2875	1427
6	2.009	.507	2650	1320	2.014	.511	2800	1390
7	2.000	.509	2700	1350	2.011	.533	2945	1464
8	2.001	.514	2800	1400	2.003	.512	1500	749*
9	2.003	.512	--	--	2.015	.511	2435	1208
10	1.992	.513	2850	1432	2.015	.517	3005	1491
11	2.000	.508	2950	1475				
			Average	1391			Average	1362

All specimens failed in bearing except specimen No.4 which ruptured acrylic sheet at the inner edge of the tongue.

All specimens failed in bearing.

	--STS-005 (75°F)--				--STS-005 (-65°F)--			
Spec. No.	Width	Thick-ness	Lbs. Pulled	Lbs/inch of Width	Width	Thick-ness	Lbs. Pulled	Lbs/inch of Width
1	1.995	.312	1250	627	1.999	.334	1500	750
2	1.985	.302	985	497	1.998	.323	1440	721
3	1.981	.307	1100	555	1.999	.331	1440	720
4	1.982	.309	1200	605	1.996	.339	1485	744
5	1.997	.303	1225	615	1.952	.339	1425	730
6	1.982	.311	1250	630	1.999	.306	1385	693
7	1.992	.303	1300	653	2.000	.323	1545	773
8	1.995	.303	1225	615	1.998	.330	1410	706
9	1.992	.303	1150	578	2.000	.338	1510	755
10	1.998	.309	1200	600	1.998	.312	1465	733
			Average	598			Average	733

Specimen No.1 ruptured the Nylon Cloth at the lower edge of the acrylic.

	--STS-007 (75°F)--				--STS-007 (-65°F)--			
1	2.004	.523	600	299	1.994	.533	1685	845
2	1.999	.520	600	300	1.998	.534	1665	833
3	1.999	.528	775	388	1.997	.514	1640	821
4	1.999	.518	700	350	1.995	.517	1600	832
5	2.000	.531	760	380	1.997	.513	1590	796
6	2.001	.524	525	262	1.993	.511	1485	745
7	2.000	.522	600	300	1.995	.509	1555	779
8	1.997	.521	575	288	1.998	.510	1625	813
9	2.000	.530	760	380	1.995	.524	1440	722
10	1.996	.523	720	361	1.997	.527	1620	811
			Average	331			Average	800

In every case the acrylic rupture originated from the face rout.

	--STS-008 (75°F)--				--STS-008 (-65°F)--			
1	1.998	.306	1200	601	1.990	.326	1285	646
2	1.980	.307	1225	618	1.980	.292	1375	694
3	1.985	.306	1250	630	1.991	.330	1375	691
4	1.992	.306	1250	628	1.997	.320	1250	626
5	1.994	.306	1235	619	1.995	.321	1170	586
6	2.000	.304	1275	638	1.993	.331	1070	537
7	1.998	.306	1300	650	2.000	.331	1070	535
8	1.998	.303	1300	650	1.998	.332	1200	601
9	1.997	.306	1250	626	1.996	.344	1000	501
10	1.993	.306	1275	640	1.933	.292	1215	629
			Average	630			Average	605

Items 1 through 7 and item 9 failed cement line between Nylon and acrylic sheet. Item 8 ruptured acrylic above the attach. Item 10 failed in the Nylon cloth.

All specimens failed in shear between Nylon and acrylic sheet.

Spec. No.	--STS-009 (75°F)-- Width	Thick-ness	Lbs. Pulled	Lbs/inch of Width	--STS-009 (-65°F)- Width	Thick ness	Lbs. Pulled	Lbs/inch of Width
1	2.003	.300	1270	634	1.996	.501	1550	777
2	2.000	.300	1270	635	2.002	.504	1515	757
3	2.004	.300	1340	668	2.003	.507	1510	754
4	2.003	.300	1270	634	1.998	.505	1490	746
5	2.003	.300	1220	609	1.997	.507	1585	794
6	2.002	.300	1220	610	1.999	.517	1600	800
7	2.003	.300	1270	634	1.997	.506	1520	761
8	2.000	.300	1270	635	1.998	.525	1490	746
9	2.001	.300	1080	540	2.000	.518	1520	760
10	2.006	.300	1365	680	1.996	.500	1595	799
			Average	628			Average	769

In all specimens the acrylic face sheets under the cemented part of the loop cracked and shattered; then bond failed.

All specimens failed the Nylon cloth.

	--STS-010 (75°F)--				--STS-010 (-65°F)--			
1	1.992	.326	2000	1003	2.002	.333	2400	1199
2	1.992	.331	2050	1028	2.002	.340	2665	1331
3	1.993	.318	2200	1105	2.000	.308	2150	1075
4	1.992	.326	1850	928	1.996	.312	2405	1205
5	1.985	.318	2500	1260	1.995	.309	1930	967
6	1.985	.323	2350	1184	2.002	.332	2475	1236
7	1.985	.326	1750	882	1.998	.320	1940	971
8	1.987	.318	2450	1233	2.000	.318	2100	1050
9	1.987	.318	2300	1158	1.987	.332	2355	1185
10	1.987	.323	1950	982	1.991	.331	2515	1263
			Average	1076			Average	1148

	--STS-012 (75°F)--				--STS-012 (-65°F)--			
1	2.005	.306	2650	1322	1.996	.330	3210	1608
2	2.005	.309	2600	1297	1.997	.343	3050	1527
3	1.997	.299	2350	1177	2.001	.333	2955	1477
4	1.997	.297	2350	1177	1.992	.335	3055	1534
5	2.003	.308	2480	1238	1.990	.340	3050	1533
6	1.999	.303	2250	1125	1.995	.337	3265	1637
7	2.005	.311	2480	1237	1.997	.339	3260	1632
8	2.000	.300	2480	1240	1.987	.333	3110	1565
9	2.003	.298	2384	1190	1.993	.342	2700	1355
10	2.004	.298	2432	1213	2.004	.342	2920	1457
			Average	1222			Average	1533

	--STS-013 (75°F)--				--STS-013 (-65°F)--			
Spec. No.	Width	Thick-ness	Lbs. Pulled	Lbs/inch of Width	Width	Thick-ness	Lbs. Pulled	Lbs/inch of Width
1	1.999	.523	3705	1853	2.000	.510	3400	1700
2	1.990	.521	3935	1977	1.981	.493	2895	1462
3	1.995	.524	4035	2022	1.999	.503	2700	1351
4	2.001	.522	3110	1555	1.996	.498	2730	1368
5	2.004	.524	3790	1890	2.000	.497	2865	1433
6	1.990	.509	3355	1686	1.995	.497	2665	1336
7	2.000	.512	3550	1775	1.998	.502	2865	1434
8	2.003	.511	3450	1772	2.000	.503	2615	1308
9	1.990	.498	3450	1732	2.000	.496	2860	1430
10	2.005	.514	3650	1820	2.005	.475	2675	1334
			Average	1803			Average	1416

In specimens 2, 7, and 10 the Fiberglas laminate failed in bearing.

	--STS-014A (75°F)--				--STS-014A (-65°F)--			
1	1.997	.313	3210	1607	1.987	.294	3200	1611
2	2.002	.295	3210	1604	1.985	.309	4120	2076
3	1.975	.314	2965	1502	1.992	.327	2775	1393
4	1.999	.315	3110	1555	1.995	.336	3250	1629
5	1.994	.315	3210	1610	1.997	.337	3225	1615
6	1.992	.296	2965	1488	1.983	.335	3150	1589
7	2.000	.297	2565	1283	1.998	.333	3245	1624
8	1.985	.295	2575	1297	1.996	.338	3495	1751
9	2.001	.314	2870	1435	1.995	.331	2560	1283
10	2.004	.313	3065	1530	1.998	.325	3350	1677
			Average	1491			Average	1605

	--STS-015 (75°F)--				--STS-015 (-65°F)--			
1	2.004	.514	2480	1237	1.997	.517	4025	2016
2	1.998	.515	2480	1241	2.005	.527	3755	1873
3	2.002	.517	2720	1358	1.998	.531	4225	2115
4	2.003	.493	3115	1555	2.005	.494	4730	2359
5	2.001	.510	2870	1434	1.998	.496	3630	1817
6	2.003	.502	3110	1552	2.000	.512	4390	2195
7	2.009	.500	2820	1404	1.999	.529	3710	1856
8	2.000	.509	3450	1725	1.996	.530	4250	2129
9	2.008	.512	3210	1599	2.009	.518	3940	1961
10	1.996	.508	3115	1560	2.004	.529	3790	1891
			Average	1467			Average	2041

--STS-022 (75°F)-					--STS-022 (-65°F)--			
Spec. No.	Width	Thick-ness	Lbs. Pulled	Lbs/inch of Width	Width	Thick-ness	Lbs. Pulled	Lbs/inch of Width
1	2.001	.288	2720	1359	2.001	.318	4600	2299
2	1.995	.302	2965	1486	2.002	.285	3740	1868
3	2.002	.289	3060	1528	2.001	.293	4050	2014
4	1.997	.297	3545	1775	2.002	.290	3710	1853
5	2.003	.285	2670	1332	1.998	.319	3710	1857
6	2.000	.285	2625	1313	2.003	.321	4540	2267
7	2.003	.301	3400	1697	2.002	.292	3800	1898
8	1.991	.297	3200	1607	2.003	.330	4680	2336
9	2.005	.307	3075	1533	2.005	.322	4650	2319
10	2.003	.313	3000	1497	2.001	.336	3615	1807
			Average	1512			Average	2052

--STS-023 (75°F)--					--STS-023 (-65°F)--			
1	2.002	.514	2460	1228	2.003	.512	5495	2743
2	1.998	.520	3240	1622	2.004	.519	5115	2552
3	2.001	.504	2200	1100	2.003	.521	5590	2791
4	2.001	.504	2510	1255	2.003	.509	5850	2921
5	2.004	.506	2430	1213	2.003	.521	5775	2883
6	2.009	.507	2280	1135	2.001	.500	5525	2761
7	2.004	.504	1985	990	1.998	.520	5565	2785
8	2.000	.508	2600	1300	1.998	.520	5320	2663
9	1.998	.502	2135	1068	1.995	.504	5575	2795
10	2.006	.505	2300	1147	1.998	.511	5620	2813
			Average	1206			Average	2771

APPENDIX IV

TENSILE-FATIGUE DATA

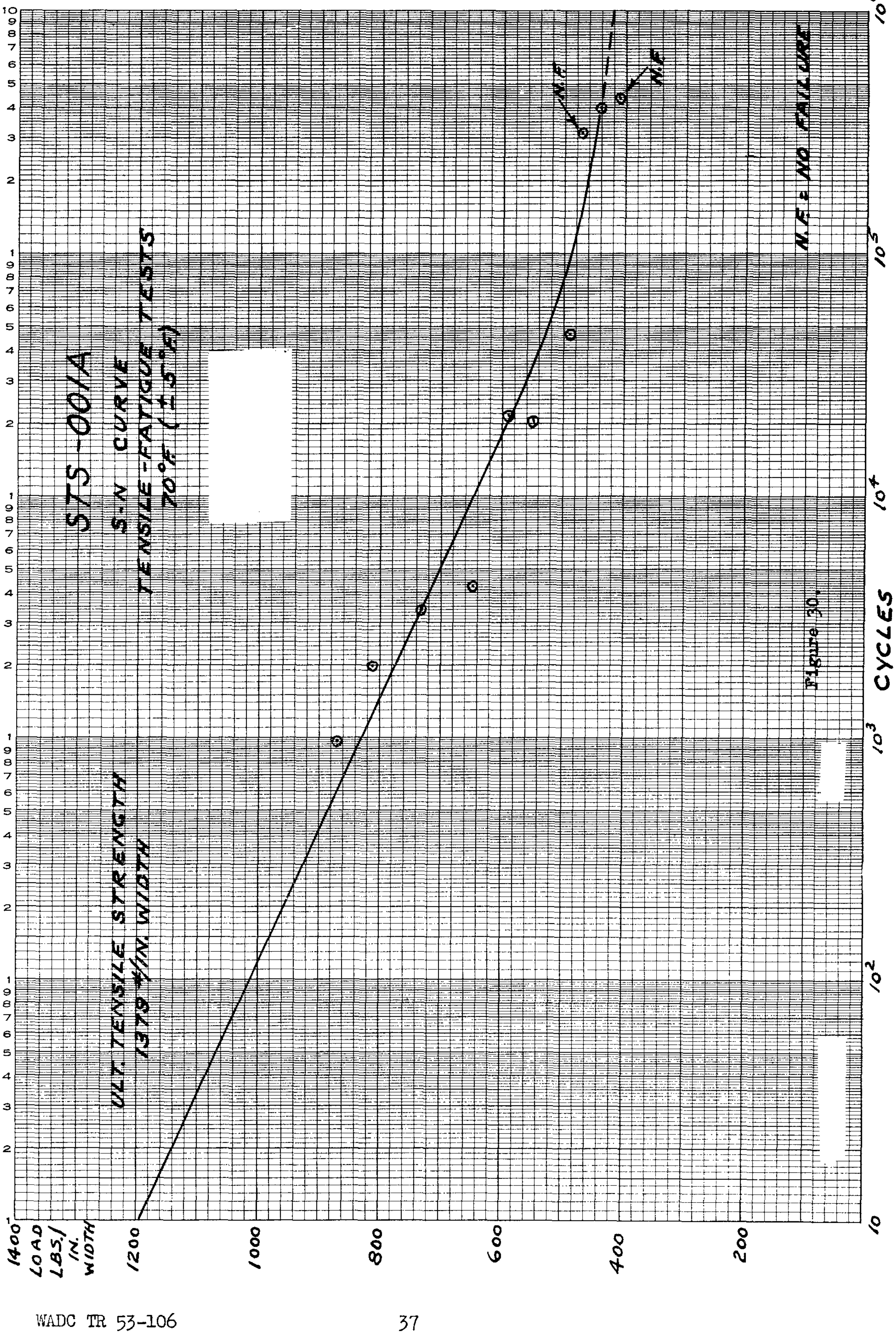
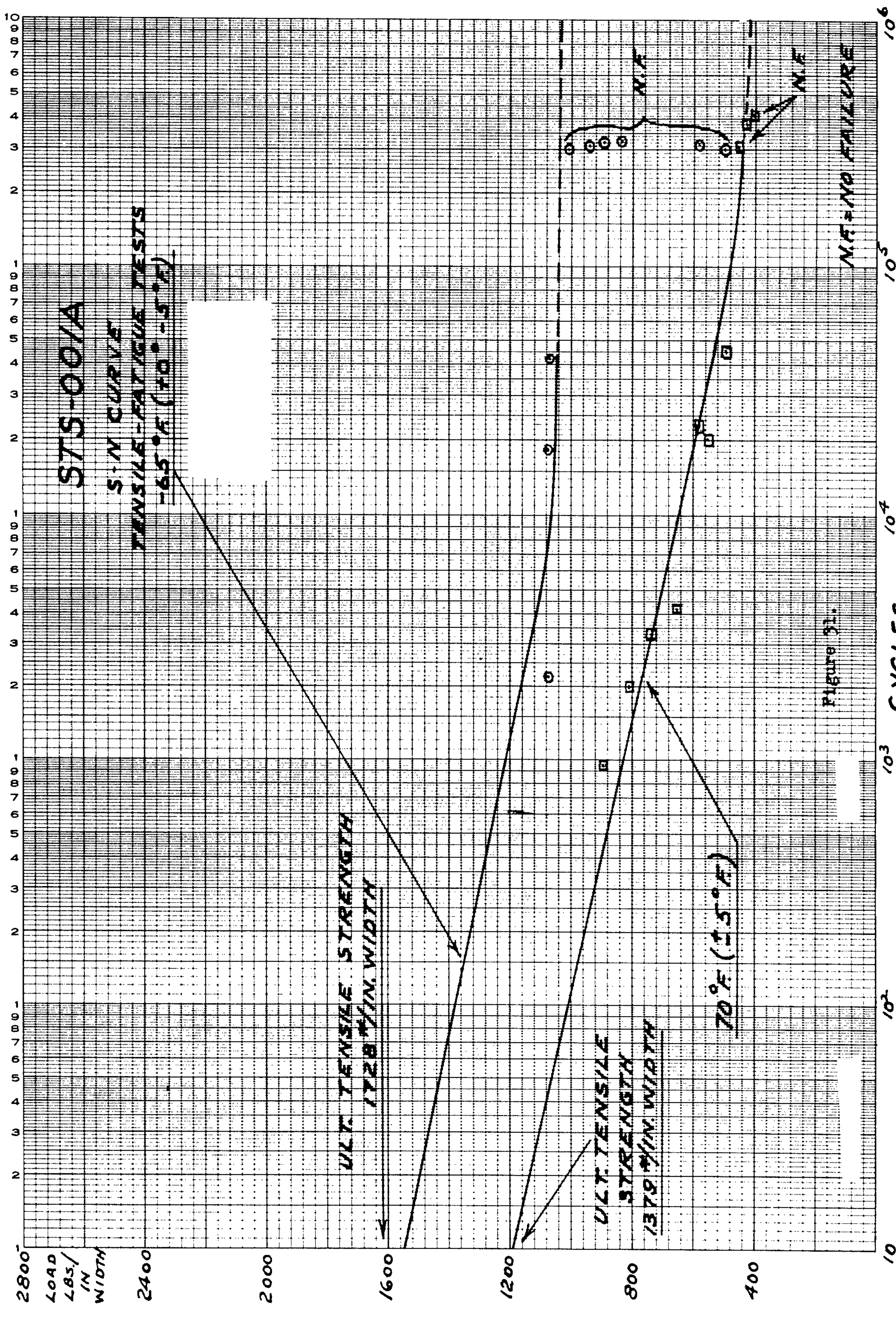

STS-001A
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (±5°F)
ULT. TENSILE STRENGTH
1379 #/IN. WIDTH
N.F. = NO FAILURE
N.F.
N.F.
CYCLES
LOAD LBS./IN. WIDTH
1400
1200
1000
800
600
400
200
10
10^2
10^3
10^4
10^5
10^6

Figure 30.



STS-001A
S-N CURVE
TENSILE-FATIGUE TESTS
-65°F (+0° -5°F)
ULT. TENSILE STRENGTH
1728 #/IN. WIDTH
ULT. TENSILE
STRENGTH
1379 #/IN. WIDTH
70°F (±5°F)
N.F.
N.F.
N.F.=NO FAILURE
LOAD LBS./IN WIDTH
2800
2400
2000
1600
1200
800
400
CYCLES
10
10^2
10^3
10^4
10^5
10^6

Figure 31.

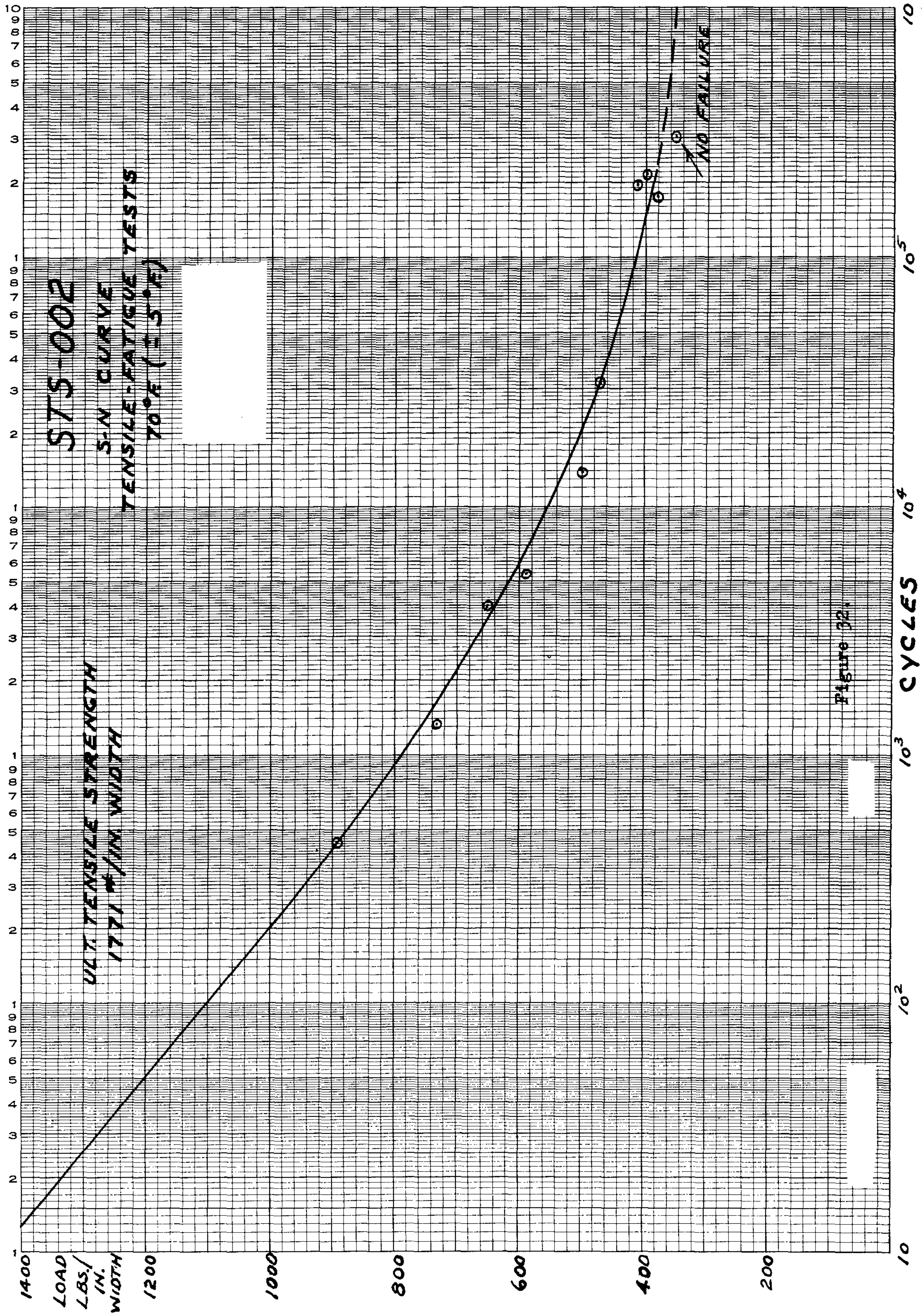

STS-002
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (± 5°F)
ULT. TENSILE STRENGTH
1771 #/IN. WIDTH
NO FAILURE
CYCLES
LOAD LBS./IN. WIDTH
1400
1200
1000
800
600
400
200
10
10²
10³
10⁴
10⁵
10⁶

Figure 32.

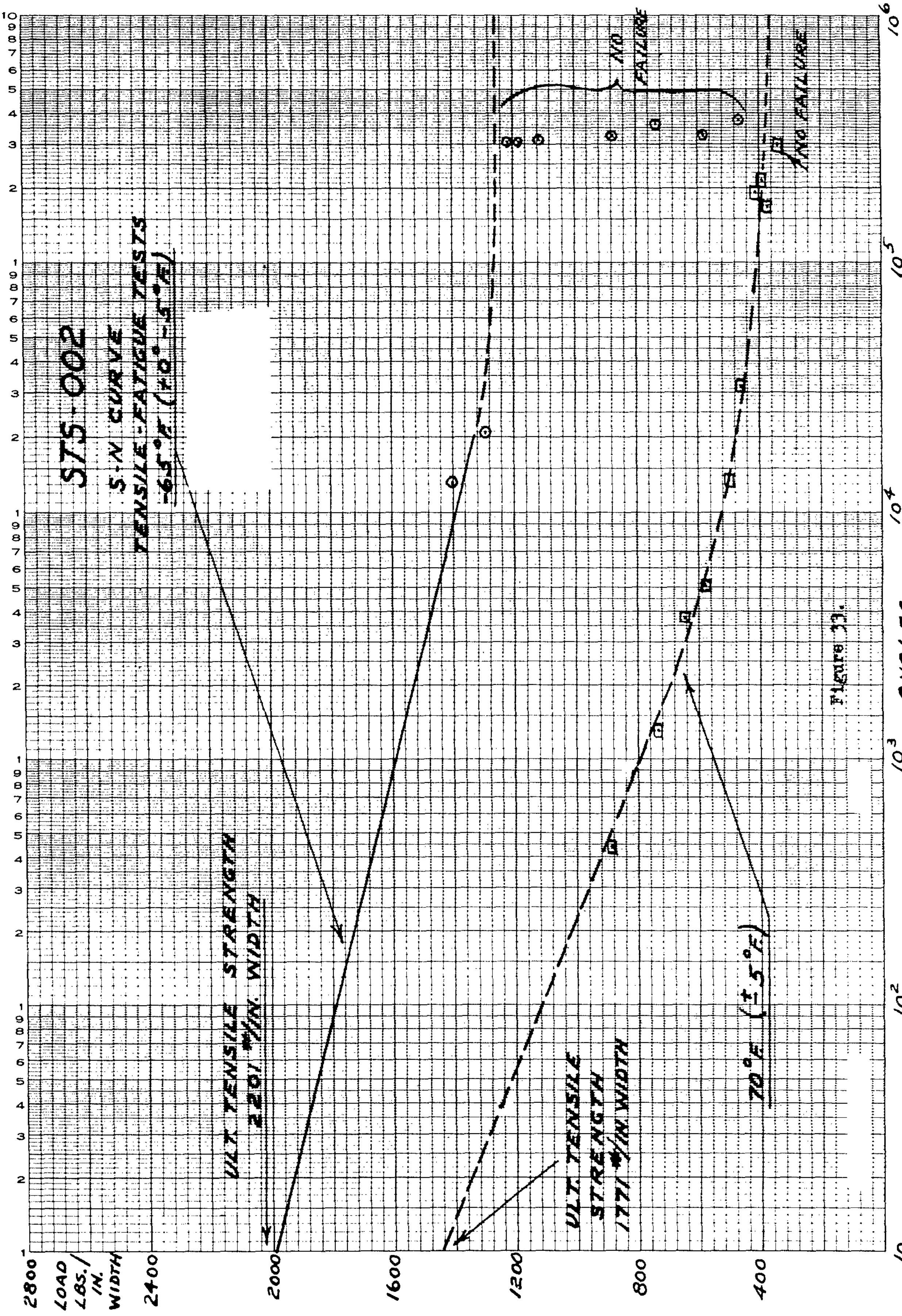

STS-002
S-N CURVE
TENSILE-FATIGUE TESTS
-65°F (+0° -5°F)
ULT. TENSILE STRENGTH
2201 #/IN. WIDTH
ULT. TENSILE
STRENGTH
1771 #/IN. WIDTH
70°F (±5°F)
NO
FAILURE
NO FAILURE
LOAD
LBS./
IN.
WIDTH
2800
2400
2000
1600
1200
800
400
CYCLES
10
10^2
10^3
10^4
10^5
10^6

Figure 33.

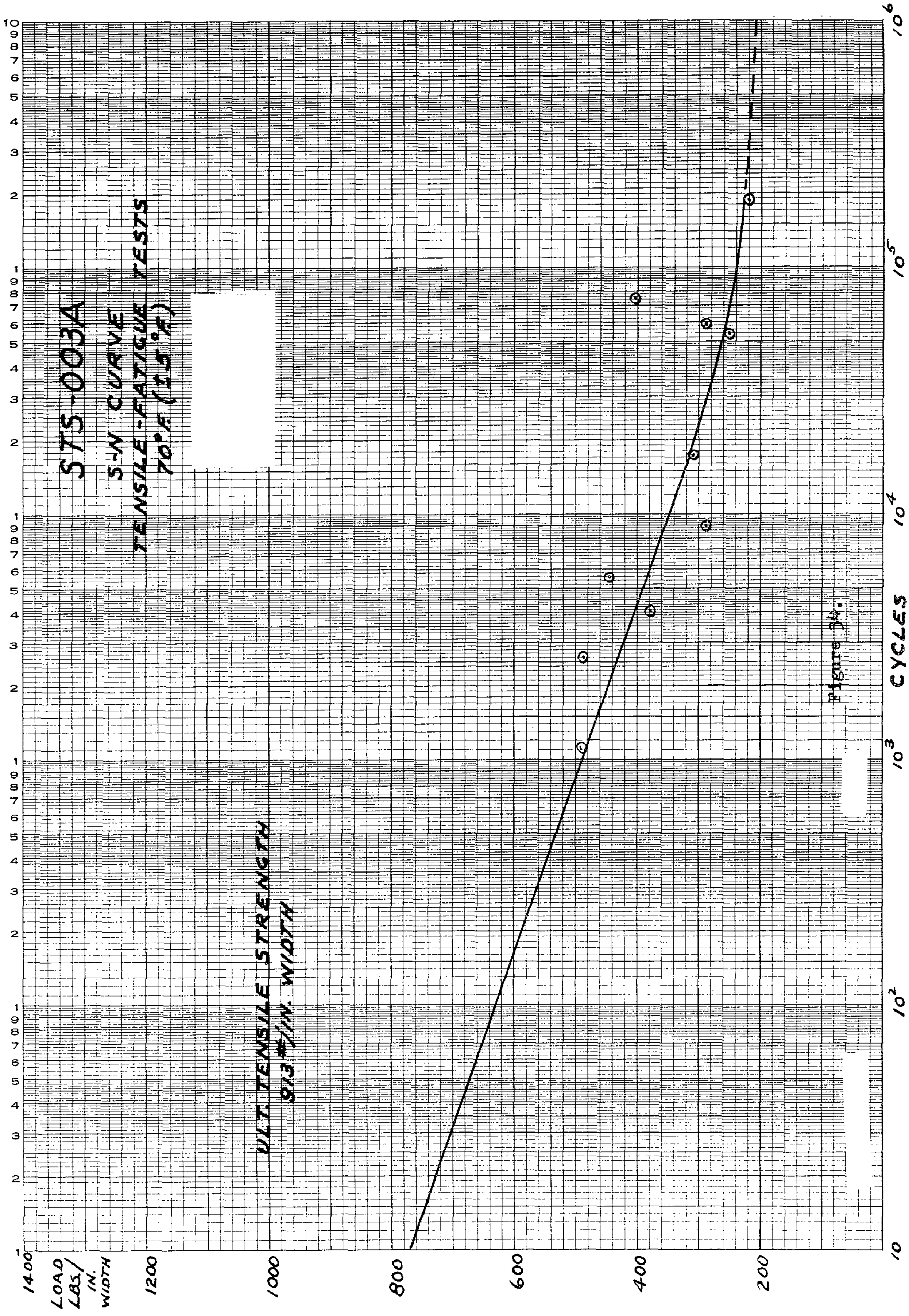
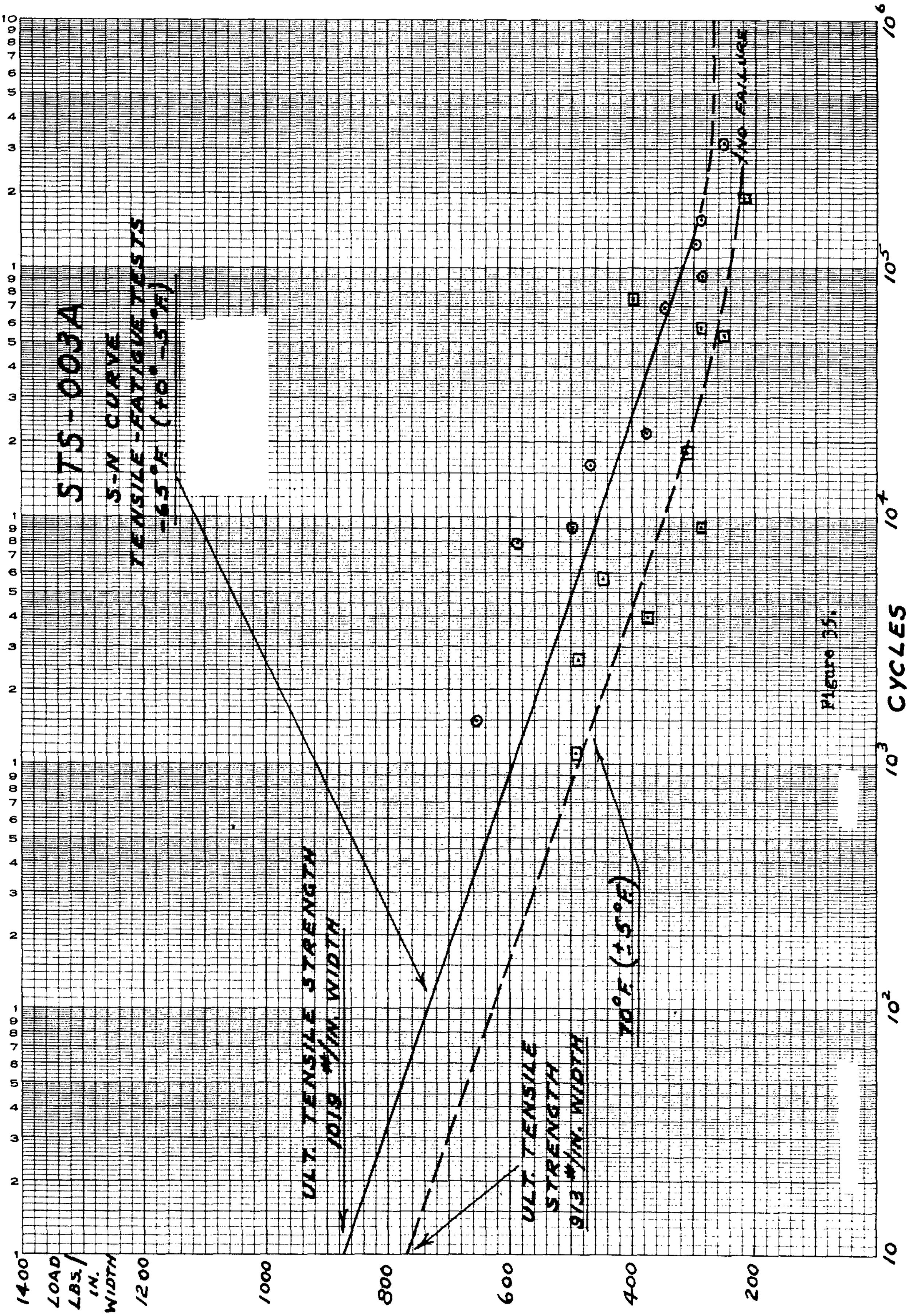

STS-003A
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (±5°F)
ULT. TENSILE STRENGTH
913 #/IN. WIDTH
LOAD LBS/IN. WIDTH
1400
1200
1000
800
600
400
200
CYCLES
10
10^2
10^3
10^4
10^5
10^6

Figure 34.


STS-003A
S-N CURVE
TENSILE-FATIGUE TESTS
-65°F (+0° -5°F)
ULT. TENSILE STRENGTH
1019 #/IN. WIDTH
ULT. TENSILE
STRENGTH
913 #/IN. WIDTH
70°F (±5°F)
NO FAILURE
LOAD
LBS./
IN.
WIDTH
1400
1200
1000
800
600
400
200
10
10^2
10^3
10^4
10^5
10^6
CYCLES
Figure 35.

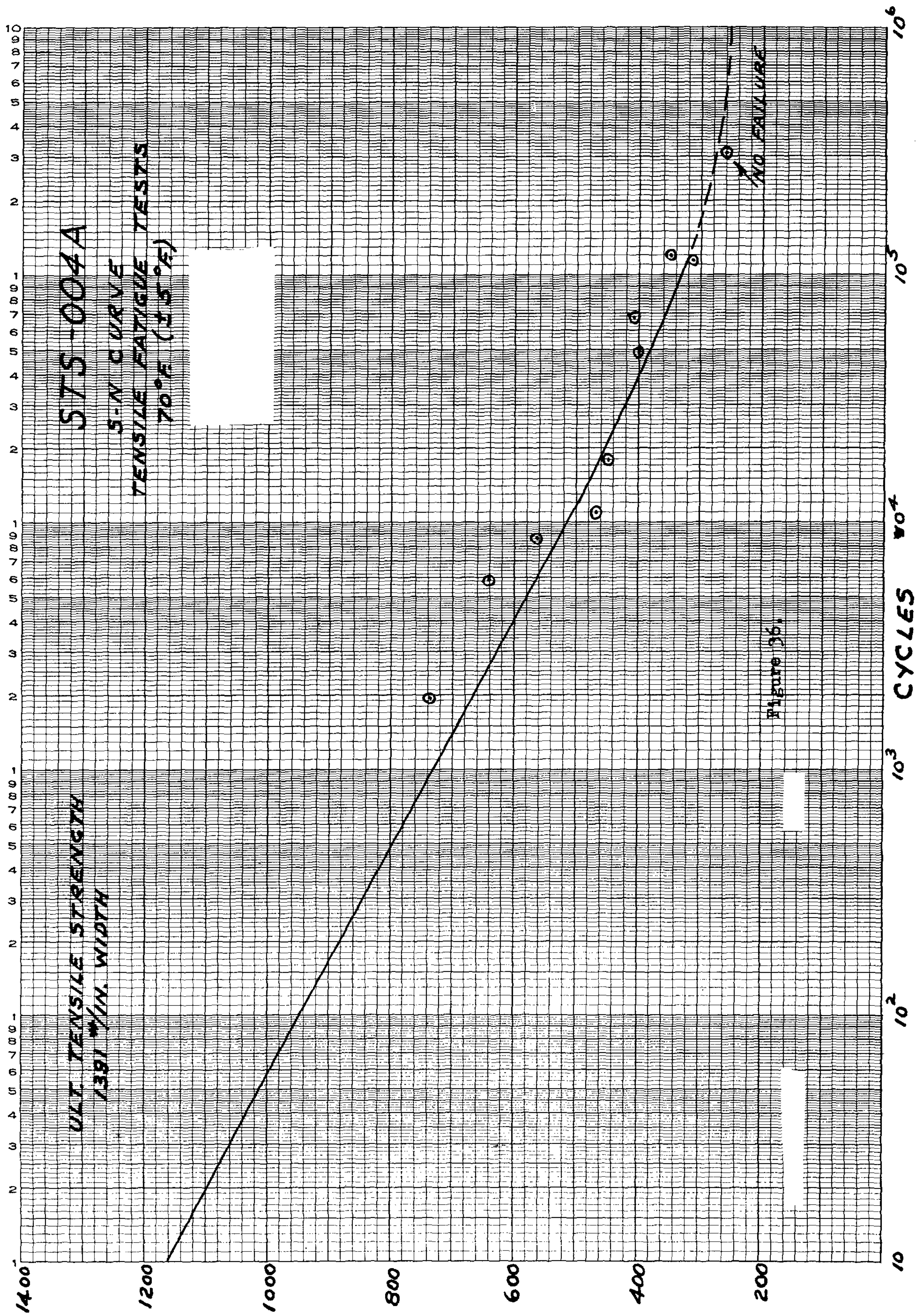

STS-004A
S-N CURVE
TENSILE FATIGUE TESTS
70°F (±5°F)
ULT. TENSILE STRENGTH
1391 #/IN. WIDTH
NO FAILURE
CYCLES
10
10²
10³
10⁴
10⁵
10⁶
1400
1200
1000
800
600
400
200

Figure 36.

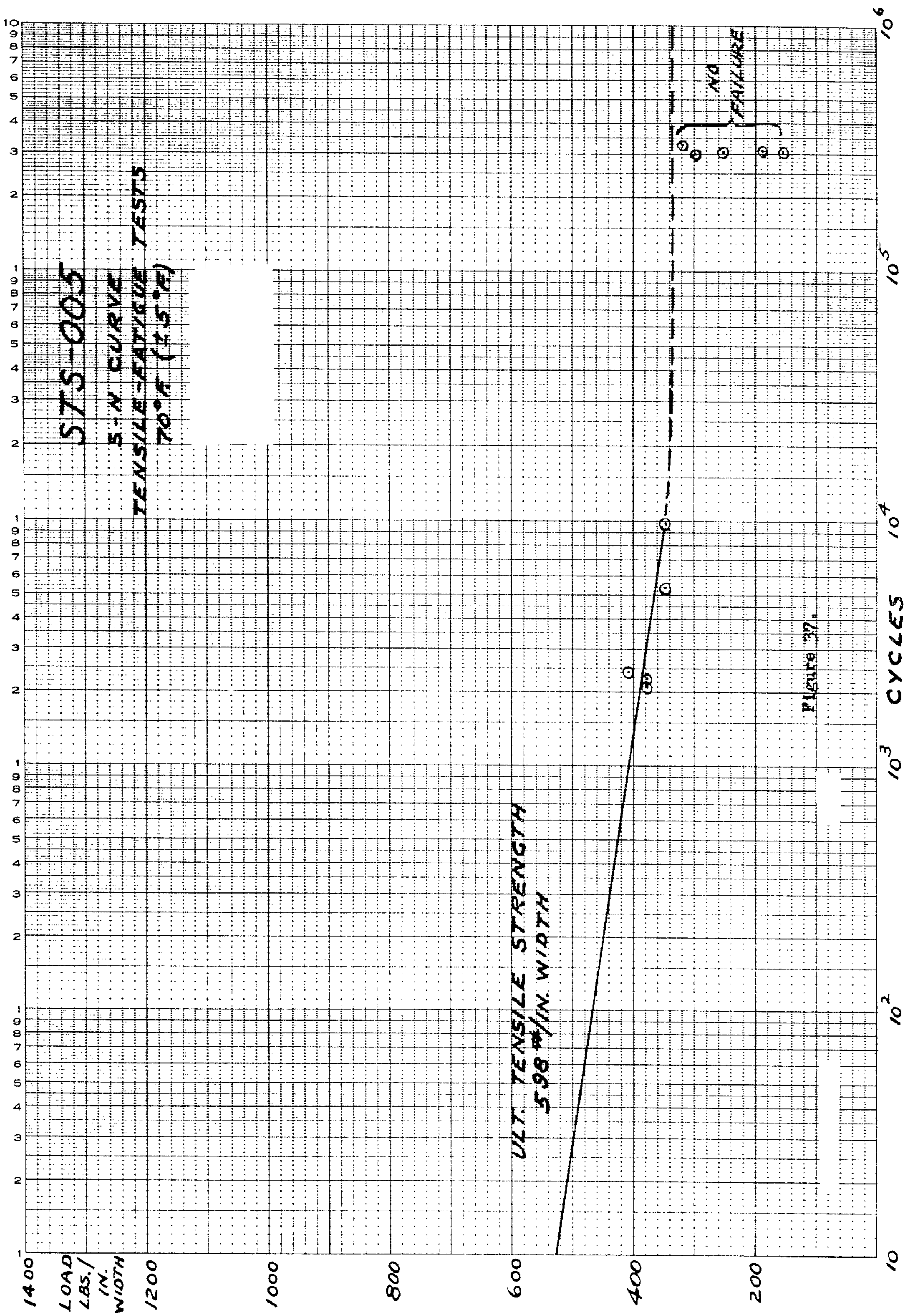
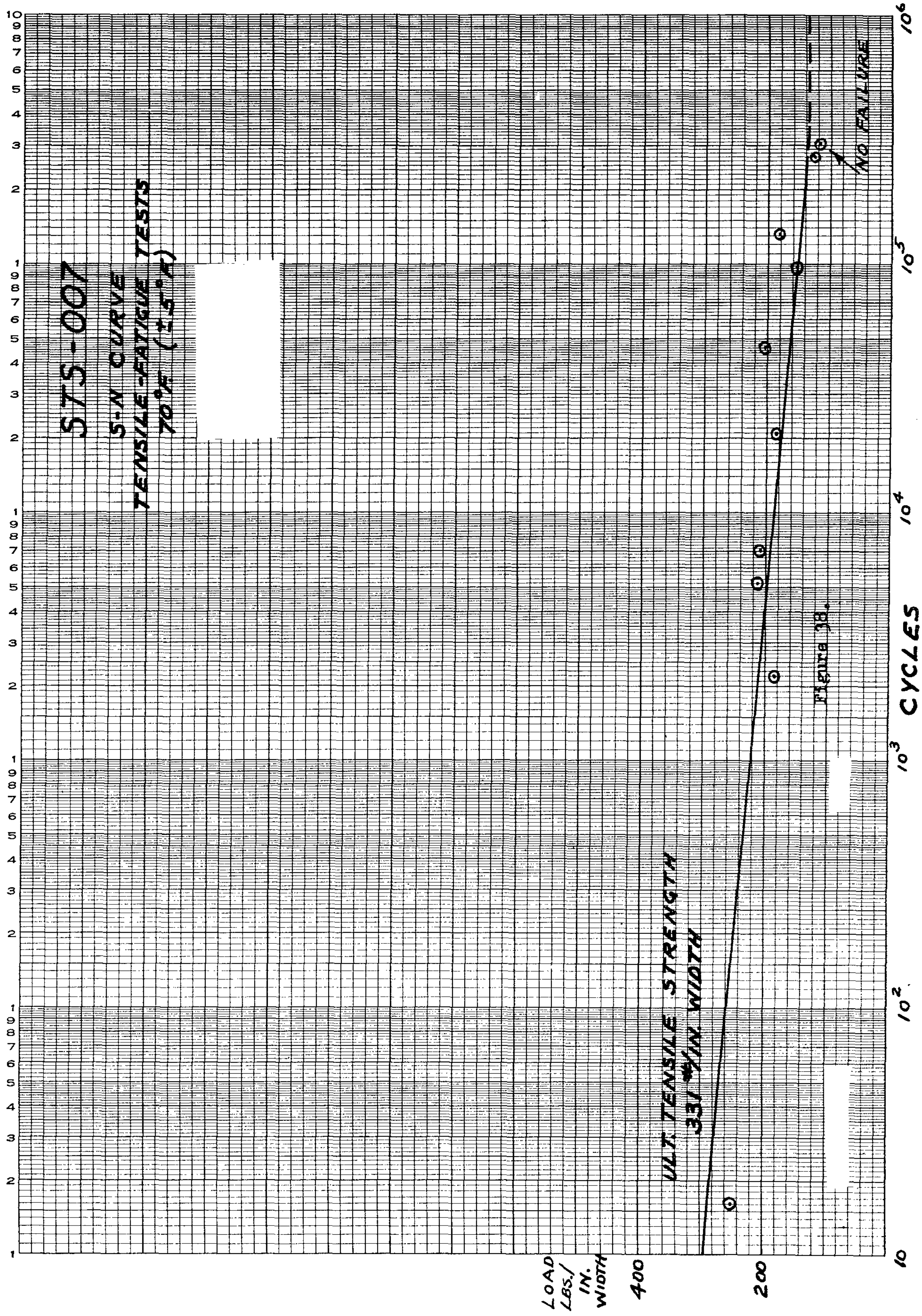

STS-005
S-N CURVE
TENSILE-FATIGUE TESTS
70°F. (±5°F)
ULT. TENSILE STRENGTH
598 #/IN. WIDTH
NO FAILURE
LOAD LBS./IN. WIDTH
CYCLES
1400
1200
1000
800
600
400
200
10
10^2
10^3
10^4
10^5
10^6

Figure 37.



575-007
S-N CURVE
TENSILE-FATIGUE TESTS
70°F. (±5°F.)
ULT. TENSILE STRENGTH
331 #/IN. WIDTH
NO FAILURE
CYCLES
LOAD LBS./ IN. WIDTH
400
200
10
10^2
10^3
10^4
10^5
10^6

Figure 38.

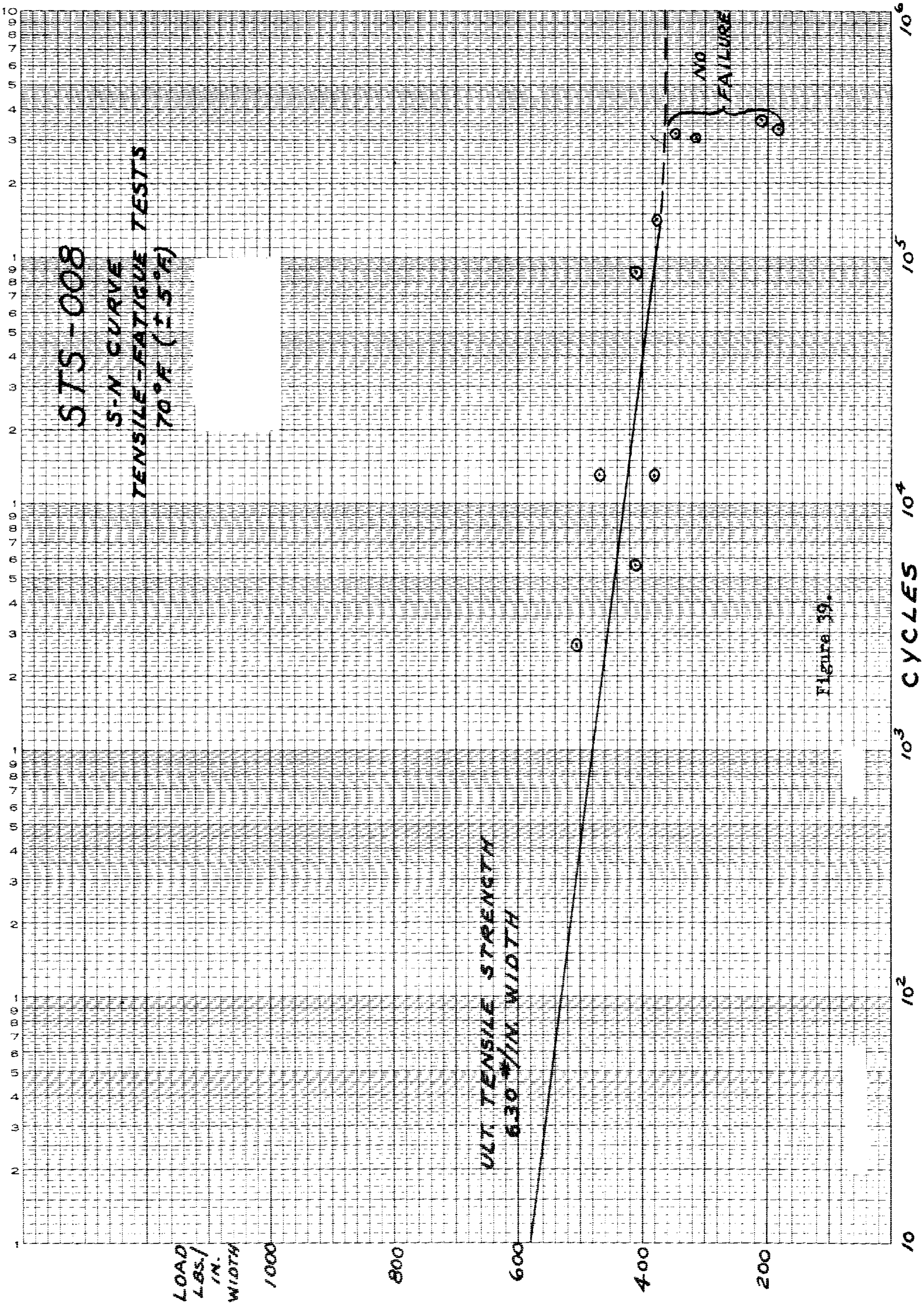

STS-008
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (±5°F)
ULT. TENSILE STRENGTH
630 #/IN. WIDTH
NO FAILURE
LOAD LBS./IN. WIDTH
1000
800
600
400
200
CYCLES
10
10^2
10^3
10^4
10^5
10^6

Figure 39.

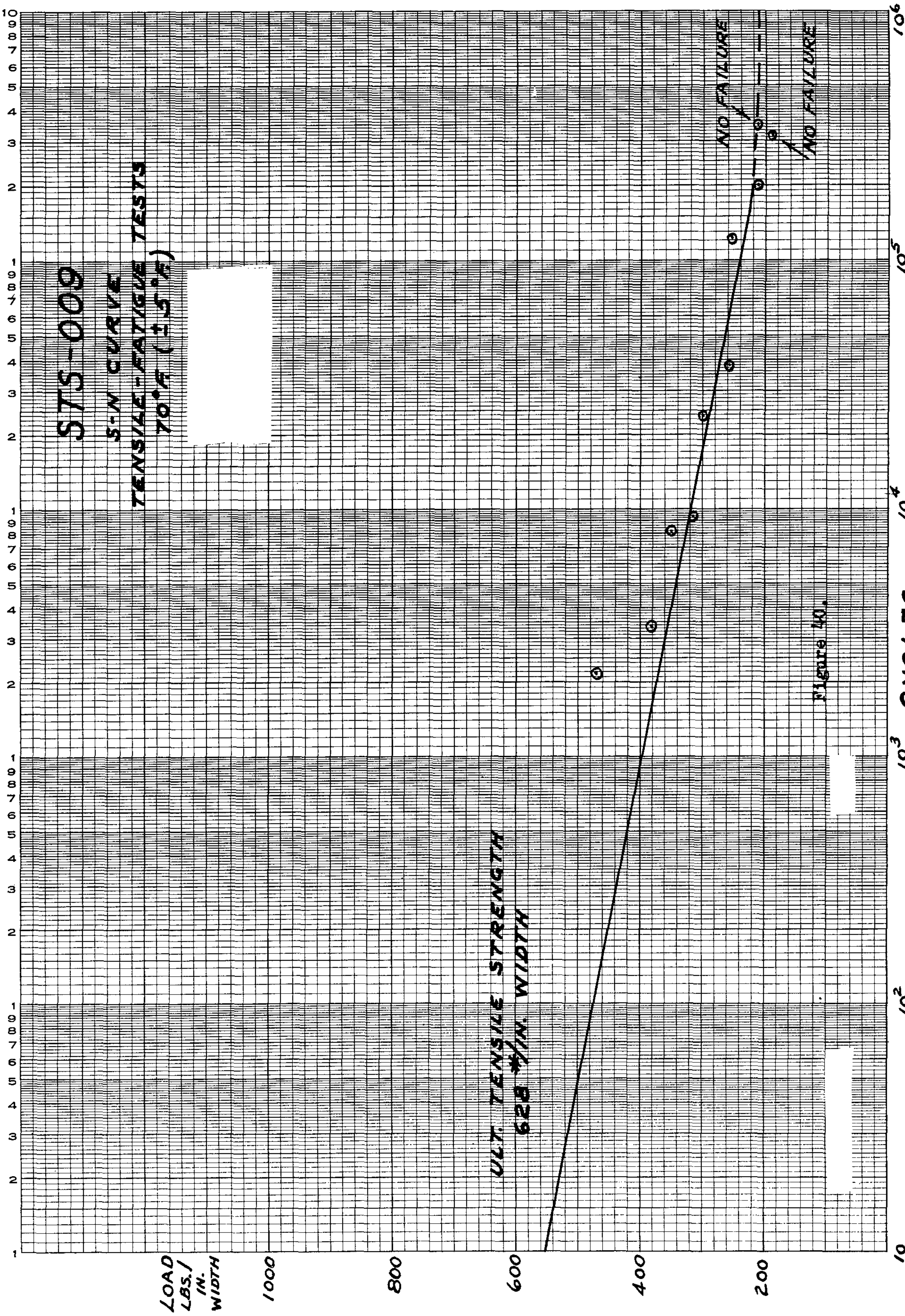

STS-009
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (±5°F)
ULT. TENSILE STRENGTH
628 #/IN. WIDTH
NO FAILURE
NO FAILURE
LOAD LBS./IN. WIDTH
1000
800
600
400
200
CYCLES
10
10^2
10^3
10^4
10^5
10^6

Figure 40.

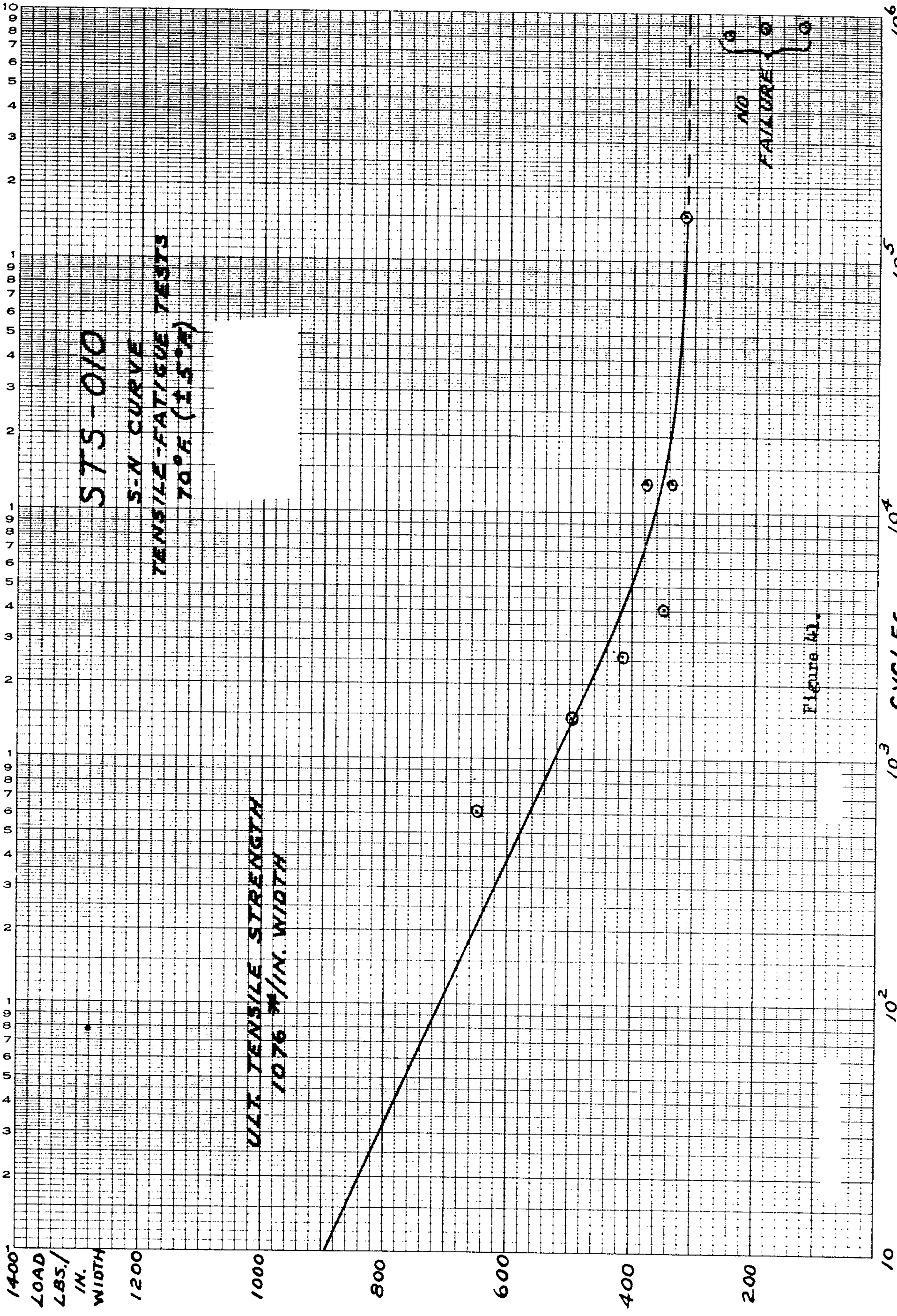

S75-010
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (±5°F)
ULT. TENSILE STRENGTH
1076 #/IN. WIDTH
NO
FAILURE
LOAD
LBS./
IN.
WIDTH
1400
1200
1000
800
600
400
200
CYCLES
10
10^2
10^3
10^4
10^5
10^6

Figure 41.

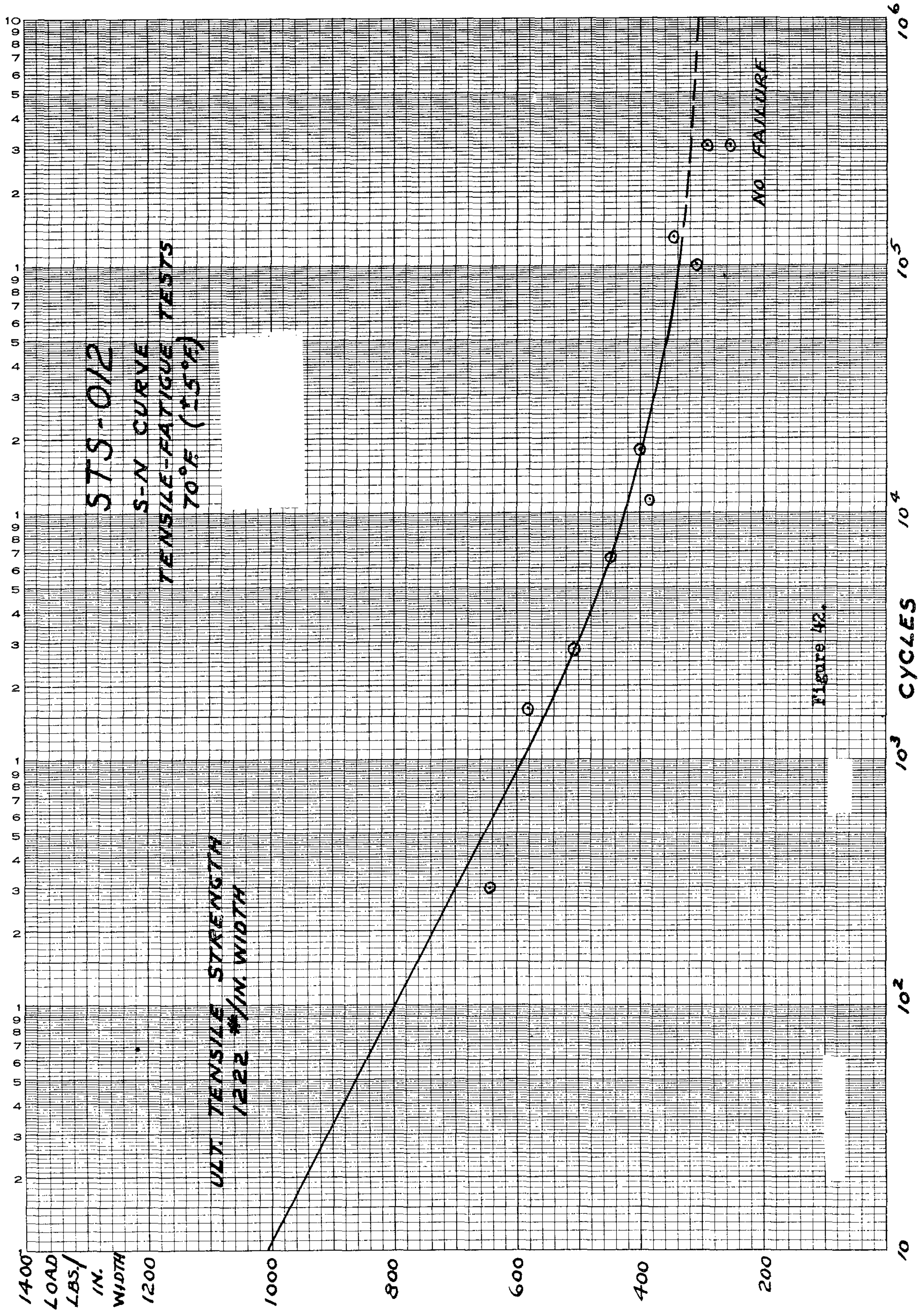

STS-012
S-N CURVE
TENSILE-FATIGUE TESTS
70°F. (±5°F.)
ULT. TENSILE STRENGTH
1222 #/IN. WIDTH
NO FAILURE
CYCLES
LOAD LBS./IN. WIDTH
1400
1200
1000
800
600
400
200
10
10^2
10^3
10^4
10^5
10^6

Figure 42.

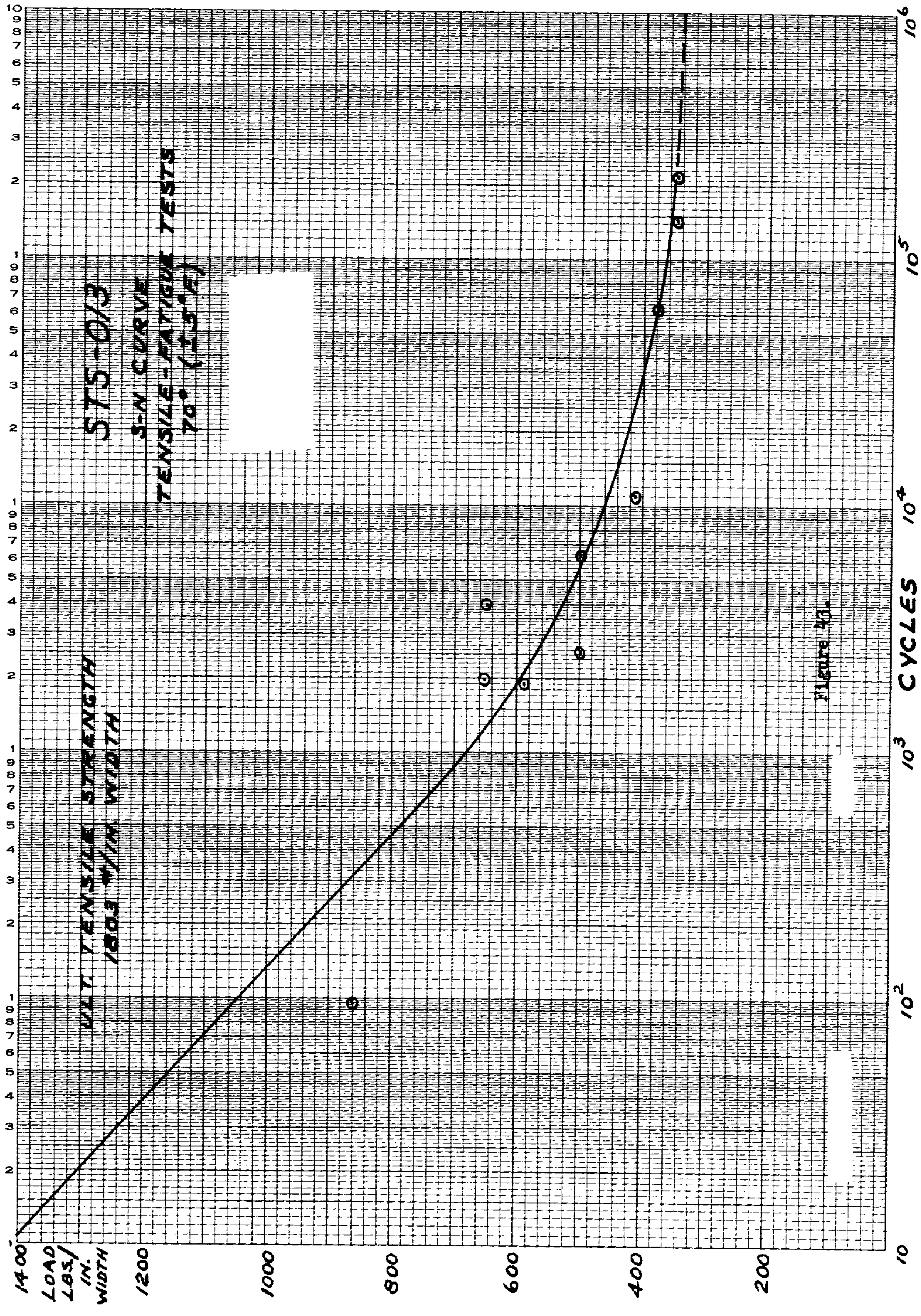
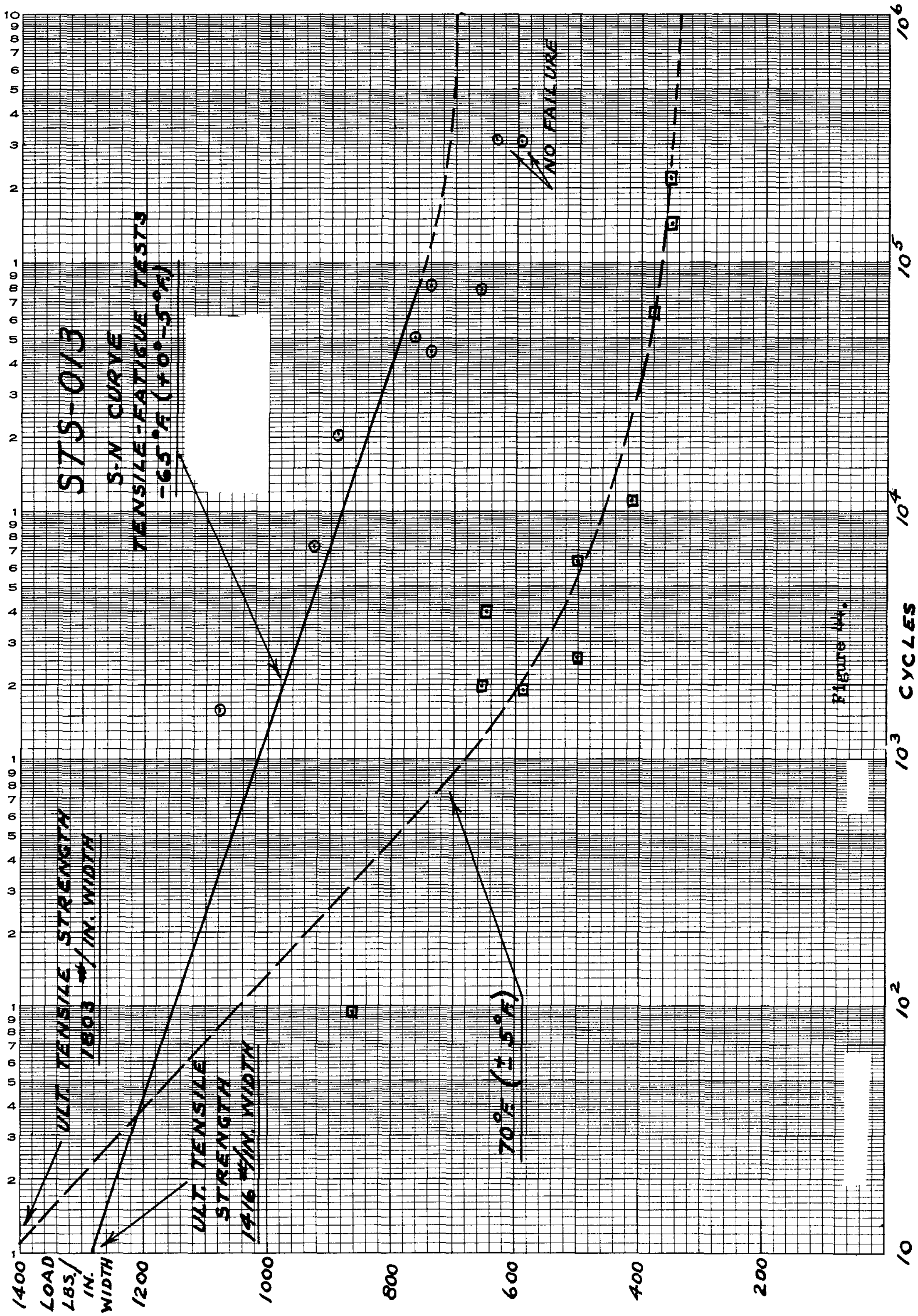
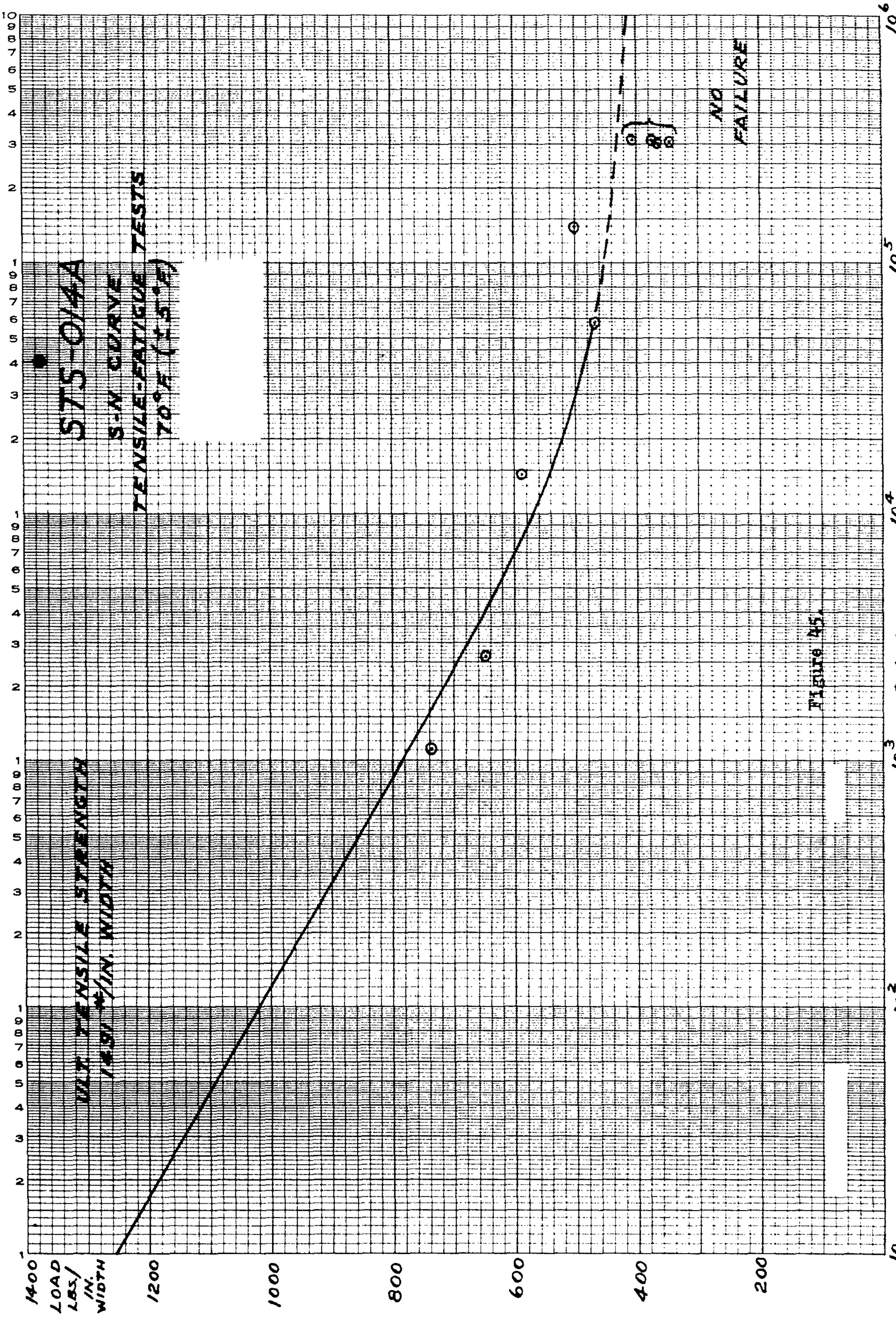

STS-013
S-N CURVE
TENSILE-FATIGUE TESTS
70° (±5°F)
ULT. TENSILE STRENGTH
1803 #/IN WIDTH
LOAD LBS/IN. WIDTH
1400
1200
1000
800
600
400
200
CYCLES
10
10^2
10^3
10^4
10^5
10^6

Figure 43.


STS-013
S-N CURVE
TENSILE-FATIGUE TESTS
-65°F (+0°-5°F)
NO FAILURE
ULT. TENSILE STRENGTH
1803 #/IN. WIDTH
ULT. TENSILE STRENGTH
1416 #/IN. WIDTH
70°F (±5°F)
LOAD LBS./IN. WIDTH
1400
1200
1000
800
600
400
200
CYCLES
10
10^2
10^3
10^4
10^5
10^6
Figure 44.



STS-014A
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (±5°F)
ULT. TENSILE STRENGTH
1291 #/IN. WIDTH
NO FAILURE
LOAD LBS./IN. WIDTH
1400
1200
1000
800
600
400
200
CYCLES
10
10^2
10^3
10^4
10^5
10^6

Figure 45.

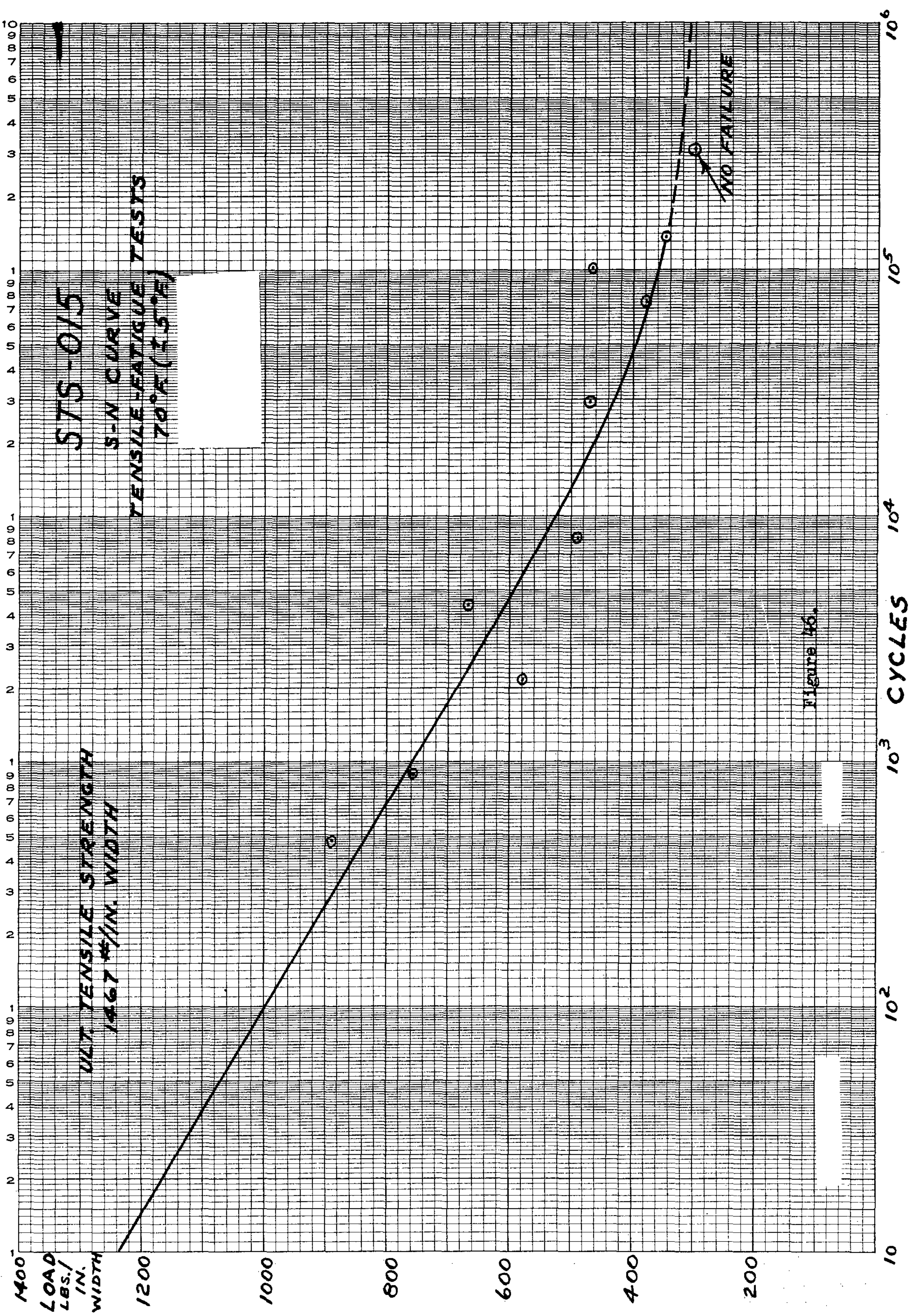

STS-015
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (± 5°F)
ULT. TENSILE STRENGTH
1467 #/IN. WIDTH
NO FAILURE
CYCLES
LOAD LBS./IN. WIDTH
1400
1200
1000
800
600
400
200
10
10^2
10^3
10^4
10^5
10^6

Figure 16.

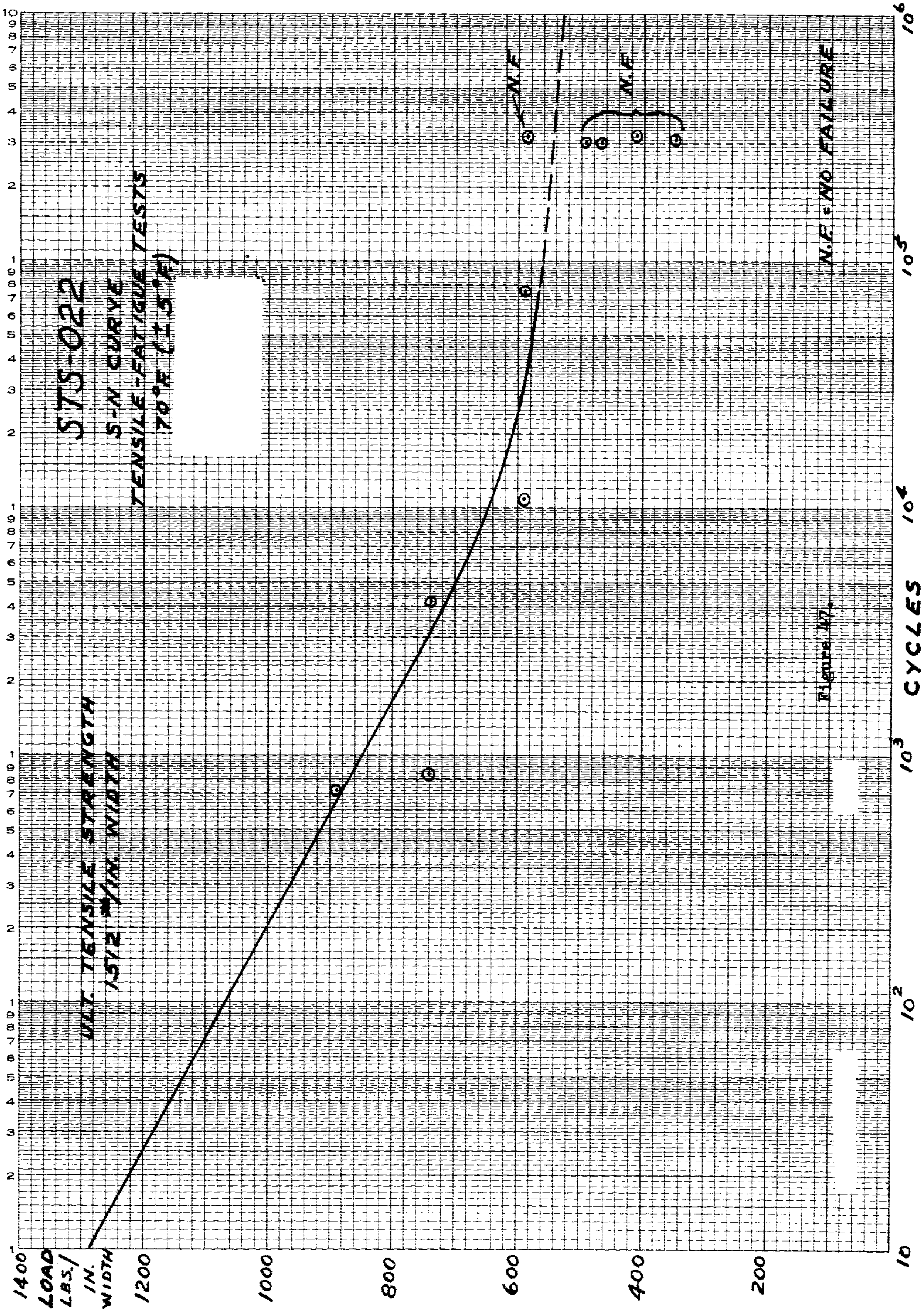

STS-022
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (±5°F)
ULT. TENSILE STRENGTH
1512 #/IN. WIDTH
N.F
N.F
N.F = NO FAILURE
LOAD LBS./IN. WIDTH
1400
1200
1000
800
600
400
200
CYCLES
10
10²
10³
10⁴
10⁵
10⁶

Figure 47.

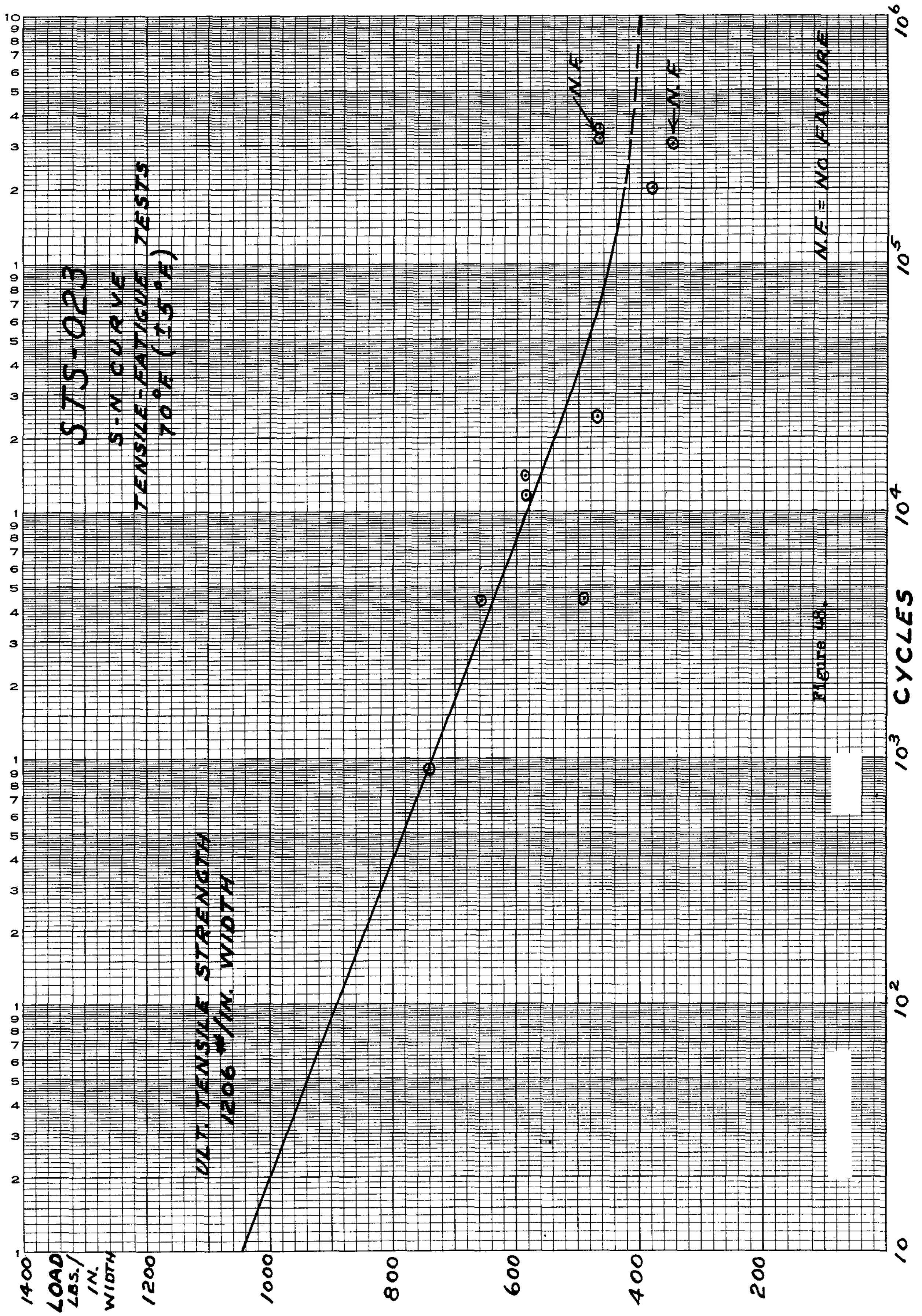

STS-023
S-N CURVE
TENSILE-FATIGUE TESTS
70°F (±5°F)
ULT. TENSILE STRENGTH
1206 #/IN. WIDTH
N.F
N.F
N.F = NO FAILURE
CYCLES
LOAD LBS./IN. WIDTH
1400
1200
1000
800
600
400
200
10
10^2
10^3
10^4
10^5
10^6

Figure 48.